PSO FOR MANAGEMENT OF TRANSMISSION CONGESTION IN A DEREGULATED POWER SYSTEM

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ABSTRACT

Congestion management is one of the most important issues for secure and reliable system operations in deregulated electricity market. This paper proposes an optimal congestion management approach in a deregulated electricity market using Particle Swarm Optimization (PSO). One of the most practiced techniques of congestion management is rescheduling the real power output of generators in the system. The values of generator sensitivity (GS) are used to select redispatched generators. Particle Swarm Optimization is used to determine the optimal generation levels and minimum redispatch cost. The effectiveness of the proposed algorithm has been analyzed on IEEE 30 bus system.

Keyword : - *Congestion management, deregulated electricity market, Generation redispatch, Generator sensitivity, optimal rescheduling, particle swarm optimization.*

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1. INTRODUCTION

Congestion or overload in one or more transmission lines may occur due to the 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. Therefore, congestion management is one of the key functions of any system operator in the restructured power industry. A number of the congestion management approaches are presented in [1]. The methods generally adopted to manage congestion include rescheduling generator outputs, supplying reactive power support, or physically curtailing transactions. System operators use the first option as much as possible and the last one as a last resort. Several techniques of congestion management have been reported [2]. In [3-4], the technique called transmission congestion distribution factors (TCDFs) is discussed. The zones are divided by active and reactive power flow sensitivity indexes. Nevethless, when all buses are considered, this technique requires a huge computational effort. A Congestion cluster-based method, which identifies the group of system users according to their impact on transmission constraints of interest, has been proposed in [3]. These clusters based on congestion distribution factors are termed as clusters of type 1, 2 and higher, where type 1 cluster represents users with strongest and nonuniform effects on transmission constraints of interest. The proposed clustering-based method has been used to create an efficient congestion management market, where the readjustment of transactions in the most sensitive cluster can help in eliminating congestion. However, this method is based on dc load flow involving the assumptions of lossless system and unity voltage magnitudes at all of the buses. A zonal model based on ac load flow was proposed in [4]. The proposed method utilizes two sets of sensitivity indexes termed as real power transmission congestion distribution factors (PTCDFs) and reactive power transmission congestion distribution congestion management in competitive power markets. The relative electrical distance (RED) method [5] allocates the desired generation change over the participants/contracts based on the RED concept (i.e., the relative locations of loads points with respect the generator points in open access). The congestion alleviation problem is not formulated as an optimization problem. All the generators in the system with sufficient flow margin are subjected to rescheduling of generation process. In [6], a technique has been proposed for alleviating congestion due to voltage instability and thermal overloads. This also uses OPF which is solved by standard solvers. 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]. The main intend of the present paper is to propose a technique for rescheduling the number of participating generators and optimum rescheduling of their outputs while managing congestion in a pool at minimum rescheduling cost. Instead of selecting all the generators to relieve congestion, this paper proposes the selection of participating generators using generator sensitivities to the power flow on congested lines. Further, it is expected to solve the congestion management problem by optimal rescheduling of the active power of participating generators employing particle swarm optimization algorithm. This paper illustrates the effectiveness of the proposed method on the congestion management problem using the IEEE 30-bus system.

2. PROBLEM FORMULATION

The objective function of the proposed method is to find an optimal profile of active power generation so as to minimize the total congestion cost, while satisfying network constraints. Based on the bids submitted by the generators for congestion management, the optimal rescheduling values of generators are computed by solving the following optimization problem. The objective function of the proposed problem is define as

$$Minimize\ \sum_{g}^{N_g} IC_g(\Delta P_g)\cdot \Delta P_g \tag{1}$$

Subjected to:
Operating limit constraints:

$$\Delta P_g^{min} \le \Delta P_g \le \Delta P_g^{max} \qquad ;g = 1, 2, \cdots, N_g \tag{2}$$

Where

$$\Delta P_g^{min} = P_g - P_g^{min} \quad and \quad P_g^{max} = P_g^{max} - P_g \tag{3}$$

Line flow constraints:

$$\sum_{g=1}^{N_g}\left(\left(GS_g^{ij}\right)\Delta P_g\right) + F_l^0 \le F_l^{max} \quad ;l = 1, 2, \cdots, n_l \tag{4}$$

Where $IC_g(\Delta P_g)$ is the incremental or decremental bid submitted by GENCO-g. ΔP_g is the real power adjustment at GENCO-g. N_g represents the number of GENCOs in the sensitive zone. F_l^0 is the power flow caused by all contracts previously settled on line-l. F_l^{max} is the line flow limit of line-l connecting buses.

The generators in the system under consideration have different sensitivities to the power flow on the congested line. A change in real power flow in a transmission line-l (connected between bus i and bus j) due to a change in power generation by generator g can be termed as generator sensitivity (GS) to the congested line. Mathematically, GS for line connected between buses i and j can be expressed as:

$$GS_g^{ij} = \frac{\Delta P_{ij}}{\Delta P_{G_g}} = \frac{\partial P_{ij}}{\partial \theta_i}\frac{\partial \theta_i}{\partial P_{G_g}} + \frac{\partial P_{ji}}{\partial \theta_j}\frac{\partial \theta_j}{\partial P_{G_g}} \tag{5}$$

The power flow equation on congested lines can be calculated by

$$P_{ij} = -V_i^2 V_{ij} + V_i V_j G_{ij}\cos(\theta_i - \theta_j) + V_i V_j B_{ij}\sin(\theta_i - \theta_j) \tag{6}$$

The differentiations of (6) with respecting to θ_i and θ_j θ_i are

$$\frac{\partial P_{ij}}{\partial \theta_i} = -V_i V_j G_{ij}\sin(\theta_i - \theta_j) + V_i V_j B_{ij}\cos(\theta_i - \theta_j) \tag{7}$$

$$\frac{\partial P_{ji}}{\partial \theta_j} = V_i V_j G_{ij}\sin(\theta_i - \theta_j) - V_i V_j B_{ij}\cos(\theta_i - \theta_j) = -\frac{\partial P_{ij}}{\partial \theta_i} \tag{8}$$

The active power injected at a bus-s which refers to any bus in the system can be calculated as

$$P_s = |V_s| \cdot \sum_{\substack{t=1 \\ t\neq s}}^{n} \{ (G_{st}\cos(\theta_s-\theta_t) + B_{st}(\theta_s-\theta_t)) \cdot |V_t| \} \tag{9}$$

$$P_s = |V_s|^2 G_{ss} + |V_s| \cdot \sum_{\substack{t=1 \\ t\neq s}}^{n} \{ (G_{st}\cos(\theta_s-\theta_t) + B_{st}\sin(\theta_s-\theta_t)) \cdot |V_t| \} \tag{10}$$

Further calculation can be linked by differentiating as

$$\frac{\partial P_s}{\partial \theta_t} = |V_s| \cdot |V_t| \cdot \{G_{st}\sin(\theta_s-\theta_t) + B_{st}\cos(\theta_s-\theta_t)\} \tag{11}$$

$$\frac{\partial P_s}{\partial \theta_t} = |V_s| \cdot \sum_{\substack{t=1 \\ t\neq s}}^{n} \{ (-G_{st}(\sin(\theta_s-\theta_t) + B_{st}\cos(\theta_s-\theta_t)) \cdot |V_t| \} \tag{12}$$

The relation between the change in active power at any bus and voltage phase angles can be written as

$$[\Delta P]_{nx1} = [H]_{nxn} \cdot [\Delta\theta]_{nx1} \tag{13}$$

$$[H]_{nxn} = \begin{bmatrix} \frac{\partial P_1}{\partial \theta_1} & \frac{\partial P_1}{\partial \theta_2} & \cdots & \frac{\partial P_1}{\partial \theta_n} \\ \frac{\partial P_2}{\partial \theta_1} & \frac{\partial P_2}{\partial \theta_2} & \cdots & \frac{\partial P_2}{\partial \theta_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial P_n}{\partial \theta_1} & \frac{\partial P_n}{\partial \theta_2} & \cdots & \frac{\partial P_n}{\partial \theta_n} \end{bmatrix}_{nxn} \tag{14}$$

Given $[M] = [H]^{-1}$ (15)

$$[M]_{nxn} = \begin{bmatrix} 0 & 0 & \cdots & 0 \\ 0 & \frac{\partial \theta_2}{\partial P_2} & \cdots & \frac{\partial \theta_2}{\partial P_n} \\ \vdots & \vdots & \ddots & \vdots \\ 0 & \frac{\partial \theta_n}{\partial P_2} & \cdots & \frac{\partial \theta_n}{\partial P_n} \end{bmatrix}_{nxn} \tag{16}$$

Thus $[\Delta\theta] = [M] \cdot [\Delta P]$ (17)

Since bus 1 is the reference bus, the first row and first column of [M] can be eliminated. Therefore, the modified [M] is written as

$$[\Delta\theta]_{nx1} = \begin{bmatrix} 0 & 0 \\ 0 & [M_{-1}] \end{bmatrix}_{nxn} \cdot [\Delta P]_{nx1} \tag{18}$$

In (18), the modified [M] represents the values of $\frac{\partial \theta_i}{\partial P_{G_g}}$ and $\frac{\partial \theta_j}{\partial P_{G_g}}$ in (5) to calculate GS values. Large GS generators will be selected for redispatch since they are more influential on the congested line.

3. PARTICLE SWARM OPTIMIZATION (PSO)

PSO is a simple and efficient populationbased optimization method proposed by Kennedy and Eberhart [7]. PSO is mo-tivated by social behavior of organisms such as fish schooling and bird flocking. In PSO, potential solutions called particles fly around in a multidimensional problem space. Population of particles is called swarm. Each particle in a swarm flies in the search space towards the optimum or quasi-optimum solution based on its own experience, experience of nearby particles, and global best position among particles in the swarm. Let us define search space S is n-dimension and the swarm consists of N particles. At time t, each particle i has its position defined by $X_t^i = \{x_1^i, x_2^i, \cdots\cdots, x_n^i\}$ and a velocity defined by $V_t^i = \{v_1^i, v_2^i, \cdots\cdots, v_n^i\}$ in variable space S. Position and velocity of each particle changes with time. Velocity and position of each particle in the next generation (time step) can be calculated as

$$V_{t+1}^{i} = \omega \times V_{t}^{i} + c_1 \times rand\,(\,) \times \left(P_{t}^{i} - X_{t}^{i}\right) + c_2 \times rand\,(\,) \times ((P_{t}^{i,g} - X_{t}^{i}) \tag{19}$$

$$X_{t+1}^{i} = X_{t+1}^{i} + V_{t+1}^{i} \tag{20}$$

Where, N = Number of particles in the swarm;

ω = Inertia weight of the particle;

n = Number of elements in a particle;

t = Generation number;

c_1, c_2 = Acceleration number;

rand ( ) = Uniform random value in the range [0, 1];

$P_{t}^{i,g}$ = Global best position in the population;

P_{t}^{i} = Best position of particle i so far.

The inertia weight ω is an important factor for the PSO's convergence. It is used to control the impact of previous history of velocities on the current velocity. A large inertia weight factor facilitates global exploration (i.e., searching of new area) while small weight factor facilitates local exploration. Therefore, it is wise to choose large weight factor for initial iterations gradually reduce weight factor in successive iterations. This can be done by using

$$\omega = \omega_{max} - \frac{\omega_{max} - \omega_{min}}{iter_{max}} \times iter \tag{21}$$

Where ω_{max} and ω_{min} are maximum and minimum weight, respectively, iter is iteration number, and $iter_{max}$ is iter is maximum iteration allowed.

With no restriction on the maximum velocity V_{max} of the particles, velocity may move towards infinity, If V_{max} is very low, particle may not explore sufficiently, and if V_{max} is very high, it may oscillate about optimal solution. Velocity clamping effect has been introduced to avoid the phenomenon of "swarm explosion". In the proposed method, velocity is controlled within a band as

$$V_{max,t} = V_{max} - \frac{V_{max} - V_{min}}{iter_{max}} \times iter \tag{22}$$

Where $V_{max,t}$ is maximum velocity at generation t, V_{max} and V_{min} are initial and final velocity, respectively. Acceleration constant c_1 is called cognitive parameter, pulls each particle towards local best position; whereas constant c_2 is called social parameter, pulls the particle towards global best position. Usually c_1 equals to c_2 and ranges from 0 to 4.

4. RESULTS AND DISCUSSIONS

The IEEE 30-bus system consists of 6 generators buses, 24 load buses and 41 transmission lines. The slack bus has been assigned to Bus 1.The total real and reactive power of load is 283.4 MW and 126.2 MVAR. The network topology and the test data for the IEEE 30 Bus system can be found in [10]. Two case studies are taken for illustration purpose. Case A: Outage of line 4-6. Case B: Increase of load by 19%.

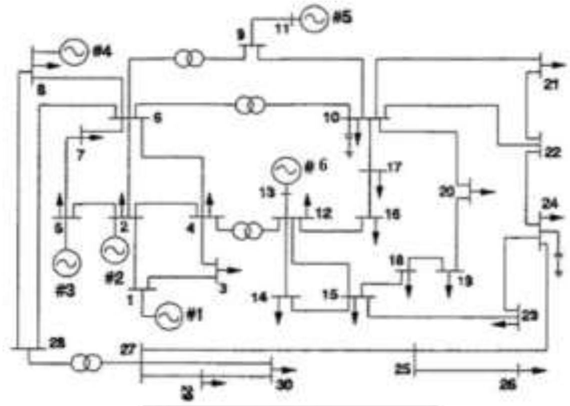

Fig - 1 Single Line Diagram for the IEEE 30-Bus System.

4.1 Case A: Outage of line 4-6

Here the power flow on all the lines in the test system due to outage of line (4-6) is determined using Newton Raphson Method.

Table - 1 Result of line flow using NR-Method – Case A

S.No.	From Bus	To Bus	Line Flow (MVA)	Line Limit (MVA)	Total power violation on (MVA)
1	1	2	133.496	130	3.496
2	2	6	69.576	65	4.576

In this case, lines such as 1-2 and 2-6 get overloaded as a consequence of line 4-6 out. The actual power flows in those lines are 133.496 MVA and 69.576 MVA (flow limit is 130 MVA and 65 MVA). For secure system, the power flow in transmission lines should not exceeds their permissible limit. Hence suitable corrective action should be carried out to alleviate the above said overloads. [11], [12]. The main scope of proposed method is to relieve overload in the congested lines by optimal rescheduling of generators .To find the optimal value of change in generation values the problem formulated above is solved using PSO.

Generator Sensitivity Factor The values of generator sensitivities computed for the congested lines using equation (5) for the system are presented in Table 2.

Table - 2 Generator sensitivity value

G_1	G_2	G_5	G_8	G_{11}	G_{13}
0	0.9247	-0.7593	0.3724	-0.2138	-0.2784

Close values of sensitivities point out that the 30-bus system is practically a very small system compared to a realistic power network. All the generators show strong influence on the congested line flow. This is because a small system is generally very ightly connected electrically. Thus, all the generators are chosen to participate in congestion management and the next part of the algorithm, i.e., solving the congestion management problem using PSO has been preceded with Generator sensitivity values of generator.

4.2 Parameter Selection of PSO

In this work, the values of ΔPg of generators 2 to 6 (except slack generator 1) are taken as control variables which constitute one particle. The set ΔPg of values are generated randomly within the limit such that equation (2) is satisfied. Then slack bus generation is computed using NR power flow. If it is not feasible (exceeds their limit) then the corresponding particle is regenerated. This is repeated for entire particles (say 50) in the population .The set of feasible solutions (size 50×5) are treated as initial population for PSO. The performance of PSO greatly depends on three parameters such as cognitive parameter and social parameter C1 ,C2 and weight factor Wmin and Wmax .The balance among these factors determines the balance between local and global searching capability. Hence, for different values of this parameter, the proposed problem is solved using PSO.

Table - 3 The parameter settings for PSO

Social Factor, C_1	Cognitive Factor, C_2	Min Inertia Weight Factor, W_{min}	Max Inertia Weight Factor, W_{max}	Number of Particles
2	2	0.4	0.9	50

Table - 4 Contribution of generators for congestion management – Case A

Generator	During Congestion	Rescheduling Details	After Congestion
	Generation on P_g (MW)	Magnitude ΔP_g (MW)	Generation on P_g (MW)
G_2	48.790	-1.3262	47.4638
G_5	21.00	-0.3586	20.6414
G_8	25.552	9.2531	34.8052
G_{11}	13.238	0.4533	13.6913
G_{13}	12.00	4.1820	16.1820
Total Rescheduling Cost = 49.042 $/hr			

Optimal value of generation adjustment required for alleviation the overloaded in lines 1-2 and 2-6 are obtained from the above said methods and they are presented in Table 4. The best solution relieves the congestion on lines 1-2 and 2-6 completely without causing overload of any other lines. The cost incurred for relieving congestion is computed using equation (1).

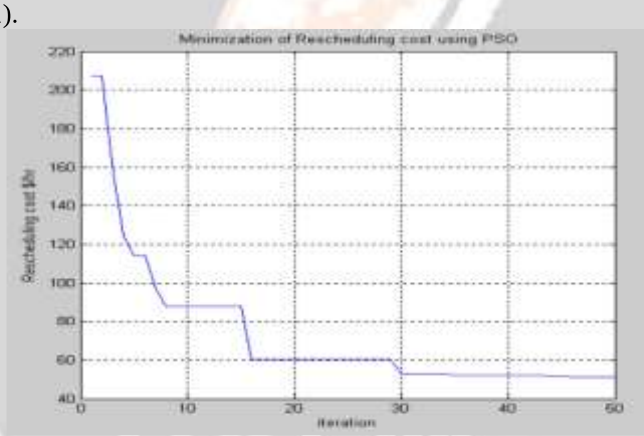

Fig - 2 Iteration Vs Rescheduling cost $/hr - Case A

Table - 5 Line power flow after congestion management-Case A

S. No.	From Bus	To Bus	Line Flow (MVA)	Line Limit (MVA)
1	1	2	119.737	130
2	2	6	60.279	65

After rescheduling the generators, the line flows are checked in the two congested lines. The line flow in the line 1-2 and 2-6 are within their line limits.

4.3 Case B: increase of load by 19%

Here the power flow on all the lines in the test system due to increase of load by 19% from their base case loads is determined using Newton Raphson Method.

Table - 6 Result of line flow using NR-Method – Case B

S. No.	From Bus	To Bus	Line Flow (MVA)	Line Limit (MVA)	Total Power Violation (MVA)
1	1	2	132.228	130	2.228

In this case, lines 1-2 get overloaded as a consequence of sudden increase of load by 19% under their base case loads. The actual power flow in line 1-2 is 132.228 MVA (flow limit is 130 MVA). For secure system, the power flow in transmission lines should not exceeds their permissible limit. Hence suitable corrective action should be carried out to alleviate the above said overloads. The main scope of proposed method is to relieve overload in the congested lines by optimal rescheduling of generators .To find the optimal value of change in generation values the problem formulated above is solved using PSO.

4.4 Generator Sensitivity Factor

The values of generator sensitivities computed for the congested lines using equation (6) for the system are presented in Table 7.

Table - 7 Generator sensitivity value

G1	G2	G5	G8	G11	G13
0	-1.203	0.6993	-0.0511	0.0348	0.1041

Close values of sensitivities point out that the 30-bus system is practically a very small system compared to a realistic power network. All the generators show strong influence on the congested line flow. This is because a small system is generally very tightly connected electrically. Thus, all the generators are chosen to participate in congestion management and the next part of the algorithm, i.e., solving the congestion management problem using PSO has been preceded with Generator sensitivity values of generator.

4.5 Parameter Selection of PSO

In this work, the values of ΔPg of generators 2 to 6 (except slack generator 1) are taken as control variables which constitute one particle. The set ΔPg of values are generated randomly within the limit such that equation (2) is satisfied. Then slack bus generation is computed using NR power flow. If it is not feasible (exceeds their limit) then the corresponding particle is regenerated. This is repeated for entire particles (say 50) in the population .The set of feasible solutions (size 50×5) are treated as initial population for PSO. The performance of PSO greatly depends o three parameters such as cognitive parameter and social parameter C1 ,C2 and weight factor Wmin and Wmax. The balance among these factors determines the balance between local and global searching capability. Hence, for different values of this parameter, the proposed problem is solved using PSO.

Table - 8 The parameter settings for PSO

Social Factor, C_1	Cognitive Factor, C_2	Min Inertia Weight Factor, W_{min}	Max Inertia Weight Factor, W_{max}	Number of Particles
2	2	0.4	0.9	50

Table - 9 Contribution of generators for congestion management-Case B

Generator	During Congestion	Rescheduling Details	After Congestion
	Generation on P_g (MW)	Magnitude ΔP_g (MW)	Generation on P_g (MW)
G_2	57.261	-4.1474	53.1135
G_5	22.309	8.3320	30.6411
G_8	35	-2.0535	32.9465
G_{11}	16.639	3.0115	19.6505
G_{13}	15.726	3.2088	18.9348
Total Rescheduling Cost = 51.243 $/hr			

Optimal value of generation adjustment required for alleviation the overloaded in lines 1-2 is obtained from the above said methods and they are presented in Table 9. The best solution relieves the congestion on line 1-2 completely without causing overload of any other lines. The cost incurred for relieving congestion is computed using equation (1).

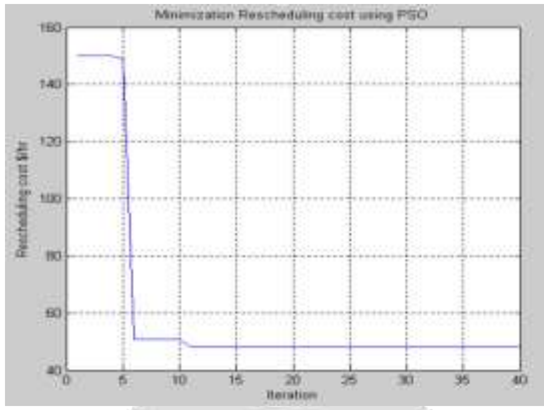

Fig - 3 Iteration Vs Rescheduling cost $/hr - Case B

Table - 10 Line power flow after congestion management -Case B

S. No.	From Bus	To Bus	Line Flow (MVA)	Line Limit (MVA)
1	1	2	125.855	130

After rescheduling the generators, the line flows are checked in the congested lines. The line flow in the line 1-2 (125.855 MVA) is within their line limit (130 MVA).

5. CONCLUSION

Thus the congestion due to line outage and sudden increase of load is relieved using real power rescheduling of generator. The rescheduling cost is minimized using Particle Swarm Optimization technique. The proposed method is tested with various line outage and load variations. However, only two cases are presented namely Case A (Outage of line 4-6) and Case B (Increase of load by 19%) for IEEE 30 bus system.

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