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Optimal Congestion Management in an Electricity Market Using Versatile Particle Swarm Algorithm

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ABSTRACT
Transmission lines in power system network operate close or beyond their thermal limits are said to be congested. In deregulated electricity markets the problem is more likely to occur due to unplanned power exchanges. Congestion management (CM) is accomplished mainly either by generator rescheduling or by load shedding. In load shedding reliability of power supply gets affected so re-dispatching the output of generator is better option to manage congestion while ensuring the system reliability. In generator rescheduling or re-dispatching independent system operators reschedule the generator output so that congestion has gotten rid off. In this operation independent system operator (ISO) commands the generator of low-price area to lower down its output while purchasing power from high price areas this will lead to an additional cost known as rescheduling cost. As rescheduling of generators incurs additional investment, an appropriate CM strategy should be adopted that involve minimum cost of generator rescheduling. This paper presents a versatile particle swarm (VPS) optimization-based CM by optimal rearranging of power generation dependent on the generator sensitivity to the congested line. In VPS algorithm, the parameters such as inertia weight factor and acceleration factors are made adaptive on the basis of objective functions of the current and best solutions. To attest the robustness and effectiveness of CM, the VPS algorithm is examined on IEEE 30-bus system and the results are compared with the particle swarm optimization (PSO) approach. The simulation results demonstrate that the VPS algorithm is successfully minimize the fuel cost in comparison with PSO for optimal rescheduling of generators to relieve congestion in the transmission line.

***Keywords* -** Congestion Management, Electricity Market, Generator Rescheduling, Particle Swarm Optimization, Sensitivity Factor.

I. INTRODUCTION

In a deregulated power system TRANSCOs, GENCOs and DISCOs are under differential organizations. To maintain the coordination between them there will be one system operator in all types of deregulated power system models, generally he is ISO. Several utilities join together to form a pool, with a central broker in place, to co-ordinate the operations on an hour-to-hour basis. In a pool market GENCOs and DISCOs submit the sell and purchase decisions in the form of sell and buy bids to the market operator, who, in turn, clears the market using an appropriate market-clearing procedure.

Vinod kumar et al. [1] clarified in detail the CM and felt that regulating the transmission framework so the move limits are watched. In a liberated environment, all the GENCOs and DISCOs prepare of time. However, when of execution of exchanges there might be congestion in a portion of the transmission lines. Thus, ISO needs to ease the clog so the system stays in secure state. Meena and Selvi [2] introduced an open transmission dispatch in which pool and respective/multi horizontal dispatches exist together and continued to build up a CM approach for this situation. Dutta et al. [3] introduced CM methods applied to different sorts of power markets. Kennady and Eberhart [4] explored widely the procedures of CM and concluded that the CM is one of the significant errands performed by ISOs to guarantee the activity of transmission framework within the limits. In the rising electric markets, the CM turns out to be critical and it can force a boundary to the power exchanging. Tooth and David [5] proposed an effective zonal CM approach utilizing real and reactive power rescheduling dependent on AC transmission congestion distribution factors addressing about the ideal distribution of reactive power. The effect of ideal rescheduling of generators and capacitors has been shown in CM.

Ashwani kumar et al. [6] depicted a planning procedure between power producing organizations and system administrator for CM utilizing Benders cuts. Lamont et al. [7] presented two methodologies for CMs because of voltage unsteadiness and thermal over-burden in a liberated environment. Hazra and Sinha [8] examined a consolidated casing work for service estimation and the CM while another methodology was employed to recognize the services of reactive help and real power misfortune for overseeing blockage utilizing the upper bound cost minimization.

Chen and Zhang [9] introduced the Particle Swarm Optimization (PSO) idea as far as its forerunners, quickly investigating the phases of its advancement from social reenactment to enhancer and examined the utilization of the approach to the neural network training. Shi et al. [10] introduced the PSO in five classifications viz. approaches, topology, parameters, modified PSO approaches and applications.

The hunt process of a PSO approach ought to be a cycle comprised of both constriction and extension so it could be able to escape from nearby minima, and inevitably discover adequate arrangements. Yamina and Shahidehpour [11] surveyed the PSO strategies and their applications to power system optimization issues. Snider et al. [12] developed the PSO for settling Optimal Power Flow (OPF) with which CM in pool market is basically executed on IEEE 30 Bus framework. Kumar and Srivastava [13] proposed cost proficient rescheduling of generation and additionally load shedding approach for CM in transmission lattices utilizing Chaotic PSO (CPSO) technique.

Christie and Wollenberg [15] PSO technique for taking care of the ED issue with the generator requirements and exhibited that the PSO strategy can evade the inadequacy of premature convergence of Genetic Algorithm (GA) technique while getting more excellent solution with better calculation effectiveness and union property.

In the recent years PSO has gained much popularity in different kind of applications because of its simplicity, easy implementation and reliable convergence. PSO is computationally inexpensive in terms of memory requirement and CPU times. PSO has been found to be robust in solving continuous non-linear optimization problems. However, the traditional PSO highly depends on its parameter and often suffers the problem of being trapped in local optima. Sakthivel et al. [16] introduced adaptive particle swarm optimization (APSO) to overcome the above problems

II. PROBLEM FORMULATION

A. OPF PROBLEM FORMULATION

In a power system, the economic operation of generating utilities is always preferred. In the deregulated market environment, the first part of the power dispatch problem is to find out the preferred schedule using OPF and the second part is rescheduling the generation for removing the congestion.

The OPF problem is about minimizing the fuel cost of generating units for a specific period of operation so as to accomplish optimal generation dispatch among operating units and in return satisfying the system load demand, generator operation constraints and line flow limits.

The objective function is corresponding to the production cost can be approximated to be a quadratic function of the active power outputs from the generating units. Symbolically, it is represented as

Minimize

$$F_t^{\cos t} = \sum_{i=1}^{N_G} f_i(P_i) \quad (1)$$

where $f_i(P_i) = a_i p_i^2 + b_i p_i + c_i$, $i = 1,2,......., N_G$ is the expression for cost function corresponding to ith generating unit and a_i , b_i and c_i are its cost coefficients. Pi is the real power output (MW) of ith generator. N_G is the number of online generating units. This constrained OPF problem is subjected to a variety of constraints depending upon assumptions and practical implications. These include power balance constraints to take into account the energy balance; feasibility of real and reactive power generation, voltage limits at load buses and line flow limits.

B. POWER BALANCE CONSTRAINTS

This constraint is based on the principle of equilibrium between total system generation and total system loads. That is given by set of non-linear power flow equations as

$$P_{G_i} - P_{D_i} - \sum_{j=0}^{n} |V_i||V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i - \delta_j) = 0 \quad (2)$$

$$Q_{G_i} - Q_{D_i} - \sum_{j=0}^{n} |V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i - \delta_j) = 0 \quad (3)$$

The real power loss in the system can be modeled a

$$P_{loss} = \sum_{k=1}^{N_l} g_k |V_i|^2 + |V_j|^2 - 2|V_i||V_j|\cos(\delta_i - \delta_j) \quad (4)$$

C. GENERATOR CONSTRAINTS

The output power of each generating unit has a lower and upper bound so that it lies in between these bounds. This constraint is represented by a pair of inequality constraints as follows.

$$P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max} \quad (5)$$

$$Q_{Gi}^{\min} \le Q_{Gi} \le Q_{Gi}^{\max} \quad (6)$$

D. VOLTAGE LIMITS

The voltage magnitudes of the each and every load bus after conducting the load flow simulation should be verified between its bounds. This voltage magnitude is having its own lower and upper bound and mathematically represented by

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

E. TRANSMISSION LINE LOADINGS

The line flows of all the transmission lines should be within its line capacity given by MVA ratings. This can be given as

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

F. DETERMINATION OF GENERATOR SENSITIVITY FACTOR

The generators in the system under consideration have different sensitivities to the power flow on the congested line. An adjustment in real power stream in a transmission line k associated between ith bus and jth bus because of progress in power generation by generator g can be named as generator sensitivity (GS) to clogged line. Mathematically, GS for line k can be written as

$$GS_g = \frac{\Delta P_{ij}}{\Delta P_g} \quad (11)$$

G. CONGESTION MANAGEMENT PROBLEM

It is advisable to select the generators having non uniform and large magnitudes of sensitivity values as the ones most sensitive to the power flow on the congested line and to participate in congestion management by rescheduling their power outputs. Based on the bids received from the participant generators, the amount of rescheduling required is computed by solving the following optimization problem.

$$C_c = \min \sum_{g}^{N_g} C_g(\Delta P_g)\Delta P_g \quad (12)$$

Subject to

$$\sum_{g}^{N_g} ((GS_g \Delta P_g) + PF_k^0 \le PF_k^{\max} \quad (13)$$

$$\Delta P_g^{\min} \le \Delta P_g \le \Delta P_g^{\max} \quad (14)$$

$$\Delta P_g^{\min} = P_g - P_g^{\min} \quad (15)$$

$$\Delta P_g^{\max} = P_g^{\max} - P_g \quad (16)$$

$$\sum_{g=1}^{N_g} \Delta P_g = 0 \quad (17)$$

where ΔPg is the real power adjustment at bus-g and Cg (ΔPg) are the incremental and decremented price bids submitted by generators and these generators are willing to adjust their real power outputs. PF_k^0 is the power flow brought about by all agreements mentioning the transmission administration. $PF_k^{\max}$ is the line flow limit of the line joining the ith bus and jth bus. Ng is the number of participating generators, N_l is the number of transmission lines in the system, $P_g^{\min}$ and $P_g^{\max}$ denotes respectively the minimum and maximum limits of generator outputs. It can be seen that the power flow solutions are not required during the process of optimization.

III. VPS OPTIMIZATION

A. PSO

PSO algorithm for N-dimensional problem formulation based on the above concept can be described as follows. Let P be the in a search 'particle' coordinate (position) and V its speed (velocity) in a search space. Consider i as a particle in the total population (swarm). Now the ith particle position can be represented as P_i= (P_{i1}, P_{i2}, P_{i3}… P_{iN}) in the N-dimensional space. The best previous position of the ith particle is stored and represented as $Pbest_i$ = ($Pbest_{i1}$, $Pbest_{i2}$ … $Pbest_{ij}$). All the Pbest are evaluated by using a fitness function, which differs for the different problems. The best particle among all Pbest is represented as gbest. The velocity of the ith particle is represented as V_i= (V_{i1}, Vi_2…. Vij).

$$V_{ij}^{(iter+1)} = W * V_{ij}^{(iter)} + c_1 * rand_1 * (Pbest_{ij} - P_{ij}^{(iter)}) + c_2 * rand_2 * (gbest_i - P_{ij}^{(iter)}) \quad (18)$$

$$P_{ij}^{(iter+1)} = P_{ij}^{(iter)} + V_{ij}^{(iter+1)} \quad (19)$$

i =1, 2… N and j =1, 2… N

The use of linearly decreasing inertia weight factor w has provided improved performance in all the applications. Its value is decreased linearly from about 0.9 to 0.4 during a run. Suitable selection of the inertia weight provides a balance between global and local exploration and exploitation, results in fewer iterations on average to find a sufficiently optimal solution, its value is set according to the following equation:

$$W = \frac{W_{\max} - (W_{\max} - W_{\min}) \times iter}{iter_{\max}} \quad (20)$$

B. VPS OPTIMIZATION

In the classical PSO, the inertia weight factor is made constant for all the particles in a single generation and the acceleration factors are made constant for all the particles in the whole generation. But these factors are very important parameters that move the current position of the particle towards its optimum position. In order to increase the search ability, the algorithm should be modified in which the movement of the swarm should be controlled by the objective function. In the proposed VPS algorithm, the particle position is adjusted such that the highly fitted particle moves slowly when compared to the lowly fitted particle. This can be achieved by using adaptive parameter values for each particle according to their objective functions of the current and best solutions.

The adaptive inertia weight factor (AIWF) is obtained as follows:

$$w_i^k = w_{\min} + \frac{C_{C_{pbest}}^{k-1} \times \left| C_{C_i}^{k-1} - C_{C_{pbest}}^{k-1} \right|}{C_{C_{gbest}}^{k-1} \times \left| C_{C_i}^{k-1} - C_{C_{g_{best}}}^{k-1} \right|} \quad (21)$$

So, the inertia weight for the best particle is set to the minimum value and vice versa. The adaptive acceleration factors are determined as follows:

$$C_{1,i}^k = \sqrt{\frac{C_{c\,i}^{\,k-1}}{C_{c\,pbest}^{\,k-1}}} \quad (22)$$

$$C_{2,i}^k = \sqrt{\frac{C_{c\,i}^{\,k-1}}{C_{c\,gbest}^{\,k-1}}} \quad (23)$$

It is concluded from Eqs. 22 and 23 that C1 and C2 values are greater than or equal to one. Higher acceleration factors are obtained for higher objective function and vice versa. Use of Eqs. 21, 22 and 23 in Eq.18 is expected to provide better optimum solution compared to classical PSO.

The VPS algorithm can be summarized as follows:

Step 1: *Initialization of the swarm:* For a particle size m, the particles are randomly generated between the minimum and maximum limits.

Step 2: *Defining the fitness function:* A suitable fitness function should be used for constraints handling based on the current.

Step 3: *Initialization of pbest and gbest:* The fitness values obtained above for the initial particles of the swarm are set as the initial pbest values of the particles. The best value among all the pbest values is identified as gbest.

Step 4: *Evaluation of adaptive inertia weight and acceleration factors:* The inertia weight and acceleration factors are computed using Eqs. 21, 22 and 23.

Step 5: *Evaluation of velocity:* The new velocity for each particle is computed.

Step 6: *Update the swarm:* The particle position is updated using Eq. 19. The values of the fitness function are calculated for the updated positions of the particles. If the new value is better than the previous pbest, the new value is set to pbest. Similarly, gbest value is also updated as the best pbest

Step 7: *Stopping criteria:* A stochastic optimization algorithm is usually stopped either based on the tolerance limit or when maximum number of generations are reached. The number of generations is used as the stopping criterion in this paper.

IV. PARAMETER SELECTION OF VPS ALGORITHM

Some parameters must be assigned before VPS algorithm is used to solve the CM problem as follows:

- Particle size = 6 and population size = 20.
- The inertia weight and acceleration factors are computed using Eqs. (21), (22) and (23).

V. RESULTS AND DISCUSSIONS

The effectiveness of the VPS algorithm has been tested for IEEE-30 bus system as shown in Fig. 1 and compared with PSO algorithm. The IEEE 30 bus system description has been given in Tables 1 and 2. The algorithms are implemented in Matlab-7.12 programming language and the developed software code is executed on 1.67 GHz, 2 GB RAM

INTEL(R) ATOM (TM) CPU (N455), DELL computer.

The preferred generation schedule corresponding to the particular load condition is obtained by running optimal power flow to minimize the generation cost alone and is given in Table 3. The generator outputs except the slack bus generator are considered as the variable for running optimal power flow. The PSO and VPS algorithms are used to optimize the generation cost. It is giving the minimum generation cost values as 801.842 $/h by VPS algorithm. The corresponding power generation is taken as the preferred schedule to meet the normal load demand. The bidding cost coefficients are given in Table 4. The congestion is created in the system by loading at load Bus-14 and is occurred in Line-26 connecting Bus-10 and Bus-17. The real power flow of the Line-26 before and after the congestion management is given in Table 5 and shown in Fig. 2. The real power flow obtained in the congested line (line-26) is 7.01 MW. But the real power flow limit of the line is 6.99 MW.

The computed generator sensitivities for the congested Line-26 are shown in Fig. 3. From the Figure it is noticed that all the generators are having strong influence on the congested line. The VPS algorithm is used for finding the necessary change in power generation to remove this congestion on Line 26. The results of rescheduling the generation by PSO, and VPS algorithms are reported in Table 6. The 20 trail is made with both the algorithms and result of best cost, worst cost and mean value of cost is presented in the same table.

Fig. 4 shows the cost of congestion management obtained by PSO and VPS algorithms. It is observed from Fig. 4 that the VPS algorithm obtains minimum cost for rescheduling of active power of participating generators to alleviate congestion.

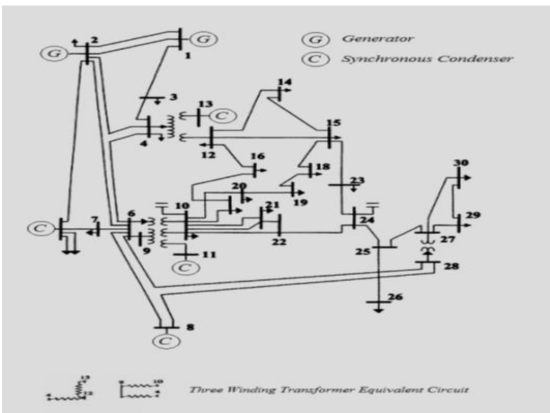

Figure 1: One-line diagram of standard IEEE-30 bus data

Table 1: *Description of the Test system*

Variables	30 bus system
Buses	30
Branches	41
Generators	6

Table 2: *Generator cost co-efficient*

Bus No.	Cost co-efficient		
	a	b	c
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

Table 3: *Active power generation before congestion management*

Generator Bus No.	Active power generation before congestion management (MW)	
	PSO	VPS
1	176.93	176.53
2	48.72	48.94
5	21.44	21.5
8	21.60	21.7
11	12.10	12.10
13	12.0	12.0
Cost($/h)	801.844	801.842

Table 4: *Bidding cost*

GEN. NO.	1	2	3	4	5	6
BIDS	11	17	19	20	15	10

Table 5: *Comparison of line flow before and after congestion management*

Branch power flow		Before congestion management active power flow (MW)	After congestion management active power flow (MW)	
From bus	To bus		PSO	APSO
10	17	7.01	6.93	6.79

Table 6: *Active power generation after congestion management*

Generator Bus No.	Active power generation before congestion management (MW)	
	PSO	VPS
1	176.15	175.95
2	47.55	51.53
5	21.45	21.91
8	24.50	22.68
11	14.5	12.6
13	12.0	12.0
Best cost (Rs/MWh)	226.53	214.97
Worst cost (Rs/MWh)	290.11	205.25
Mean cost (Rs/MWh)	260.73	220.53

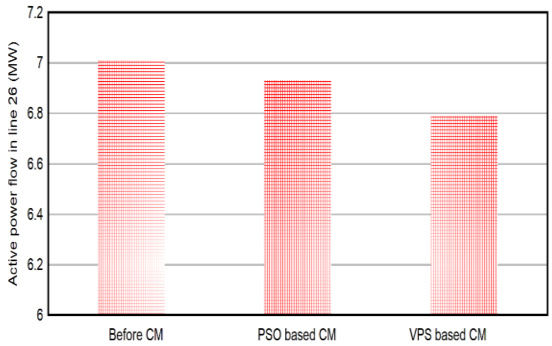

Figure 2: *Active power flows in Line 26*

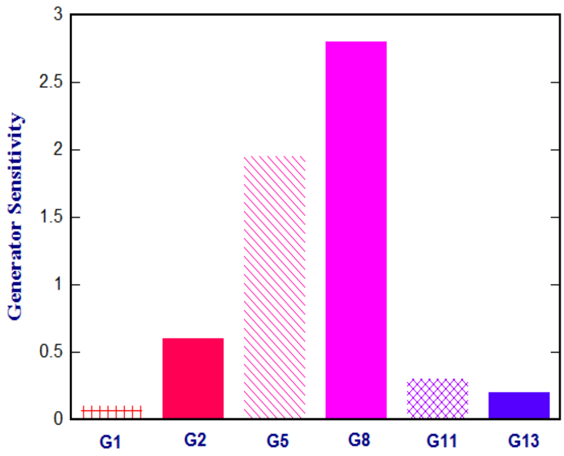

Figure 3: *Generator sensitivity factors of Line 26*

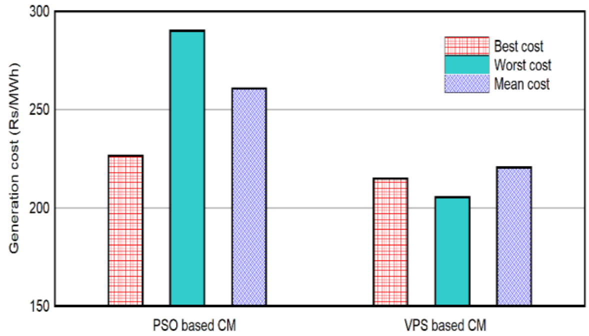

Figure 4: *Comparison of cost of generation obtained by PSO and VPS algorithms*

VI. Conclusion

In this paper, the congestion management problem has been solved through optimal rescheduling of active powers of generators utilizing PSO and VPS algorithms. The generators have been chosen based on the generator sensitivity to the congested line. The rescheduling has been carried out by taking minimization of cost and satisfaction of line flow limits into consideration. The results obtained by VPS algorithm has been tested on the IEEE 30-bus and compared with conventional PSO. Based on the results, VPS algorithm is the most cost-efficient solution to the congestion management problem compared with conventional PSO.

The following features are being suggested as future research work to be carried out.

- The effect of reactive power of generators may be considered in managing congestion.
- The VPS algorithm may be extended to solve dynamic congestion management problem.
- In recent years, the usage of renewable energy sources like wind energy and solar energy has increased drastically. So, their cost functions and constraints may be included in the OPF problem to simulate congestion management.

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