PARTICAL SWARM OPTIMIZATION FOR CONGESTION MANAGEMENT IN DEREGULATED POWER MARKET

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ABSTRACT

In competitive electricity market, congestion is a serious economic and reliability concern. Congestion is a common problem that an independent system operator faces in open access electricity market. Rapid growth of the load leads to congestion of the system. Whenever the network component is overloaded the network is called congested network.

With increasing growth of electrical power demand, electrical utilities have been forced to meet the growing power demand by increasing their generation. However the electrical power that can be transmitted between two locations is limited by several transfer limits such as thermal limit, voltage limit and stability limit. This leads to the congestion of transmission line. When the producers and consumers of electrical energy desire to produce and consume in amounts that would cause the transmission system to operate at, or beyond one or more transfer limits, the system is said to be congested. One of the most practiced and an obvious technique of congestion management is rescheduling the power outputs of generators in the system. Generation sensitivity factor has been used to identify the generators, which affects more on the congested line. However, all generators in the system need not take part in congestion management. Development of sound formulation and appropriate solution technique for this problem is aimed in this paper.

Keyword: - *Deregulation, independent system operator, generator sensitivity factor*

1. INTRODUCTION

In the deregulated power system congestion management is one of the most challenging tasks of System Operator. Due to congestion in the transmission lines, it is not always possible to deliver all of the contracted power transactions, where in both the buyers and sellers try to buy and sell electric power so as to maximize their profit. System Operators try to manage congestion, which otherwise increases the cost of the electricity and also threatens the system security and stability. To maintain the market efficiency, it is very important that the congestion be relieved in a fast, systematic and efficient manner.

In deregulated environment, the term Transmission Open-Access (TOA) indicates that the transmission network is freely available to the other market participants such as generators, customers, or other utilities that want to use the transmission network for power transaction between them and thus creates a situation in which transmission network is not able to accommodate all the desired transaction due to violations of some system constraint, this is known as congestion. Congestion may be caused due to various reasons, such as transmission line outages, generator outages and change in energy demand. Increase in power demand, unexpected outage of generation, restriction on the construction of new lines, unscheduled power flow in lines, tripping of transmission lines or failures of other equipment are some of the potential causes for congestion.

The literature survey reveals that various techniques have been used to address the serious issues related to Congestion management. The methods generally adopted to manage congestion include rescheduling generator outputs, supplying reactive power support or physically curtail transactions. System operators generally use the first option as much as possible and the last one as the last resort. Several techniques of congestion management have been reported in References [3]. The form of deregulated electric power industry differs from country to country as well as between different regions of a country. Different models to deal the different transactions, interactions

between properties and limitations of the transmission system and the economic efficiency of the energy market have been mentioned in References [4]. Congestion management techniques applied to various kinds of electricity markets are presented in References [5]. Prioritization of electricity transactions and related curtailment strategies in a system where pool and bilateral/multilateral dispatches coexist is proposed in References [6]. In References [7], congestion management ensuring voltage stability is addressed. An optimal topological configuration of a power system as a tool of congestion management is presented in References [8]. A corrective switching operation of transmission lines is used instead of generation rescheduling to alleviate congestion in this paper.
Congestion management in open access electricity market has been discussed in References [10–12]. A detailed analysis of different Congestion management techniques, used in different electricity markets throughout the world, may be found in Reference [10]. A minimum distance re-dispatch has been proposed in Reference [11] ignoring the economic value of the transaction adjustment. In Reference [12], the congestion is managed by using the marginal cost signals for the generators. Thukaram and Parthasarathy [15] have proposed an expert system based approach for the alleviation of network overloads using phase shifting transformers and generation rescheduling.

2. MATHEMETICAL PROBLEM FORMULATION

Congestion Management by generator rescheduling problem can be divided into two parts. Part I of the problem is to identify the sensitivities of the generators which contribute to the congestion of the line. Here a branch is made out to create the congestion in other lines. Part II of the problem is to reschedule the generators with minimum congestion cost. The OPF base case solution is the preferred solution as it is solved for lowest cost while considering voltage and flow limit constraints.

2.1 Generator Sensitivity Factor

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 k connected between bus i and bus j due to change in power generation by generator g can be termed as generator sensitivity to congested line (GS). Mathematically, GS for line k can be written as

$$GS_g = \frac{\Delta P_{ij}}{\Delta P_{G_g}} \quad \text{….(1)}$$

Where

ΔP_{ij} = Real power flow on congested line-k

ΔP_{G_g} = Real power generated by the gth generator

The basic power flow equation on congested line can be written as

$$P_{ij} = -V_i^2 G_{ij} + V_i V_j G_{ij} \cos(\theta_i - \theta_j) + V_i V_j B_{ij} \sin(\theta_i - \theta_j) \quad \text{….(2)}$$

Where

V_i = Voltage magnitude

θ_i = Phase angle at the ith bus

G_{ij} = Conductance

B_{ij}= Susceptance of the line connected between buses i and j

Neglecting P-V coupling, (1) can be expressed as

$$GS_g = \frac{\partial P_{ij}}{\partial \theta_i} \cdot \frac{\partial \theta_i}{\partial P_{G_g}} + \frac{\partial P_{ij}}{\partial \theta_j} \cdot \frac{\partial \theta_j}{\partial P_{G_g}} \quad \text{....(3)}$$

The first terms of the two products in (3) are obtained by differentiating (2) as follows:

$$\frac{\partial P_{ij}}{\partial \theta_i} = -V_i V_j G_{ij} \sin(\theta_i - \theta_j) + V_i V_j B_{ij} \mathrm{com}(\theta_i - \theta_j) \quad \text{...(4)}$$

$$\frac{\partial P_{ij}}{\partial \theta_j} = +V_i V_j G_{ij} \sin(\theta_i - \theta_j) - V_i V_j B_{ij} \mathrm{com}(\theta_i - \theta_j) \quad \text{....(5)}$$

$$\frac{\partial P_{ij}}{\partial \theta_j} = -\frac{\partial P_{ij}}{\partial \theta_i} \quad \text{...(6)}$$

The active power injected at a bus-s can be represented as

$$P_S = P_{G_S} - P_{D_S} \quad \text{...(7)}$$

Where P_{D_S} is the active load at bus-s. P_S can be expressed as

$$P_S = V_s \sum_{t=1}^{n} ((G_{st} \cos(\theta_s - \theta_t) + B_{st} \sin(\theta_s - \theta_t))V_t)$$

$$= (V_s 2G_{ss} + V_s) \sum_{\substack{t=1 \\ t \neq s}}^{n} ((G_{st} \cos(\theta_s - \theta_t) + B_{st} \sin(\theta_s - \theta_t))V_t) \quad \text{... (8)}$$

Where n is the number of buses in the system.

Differentiating w.r.t. θ_s and θ_t , the following relations can be obtained:

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

$$\frac{\partial P_s}{\partial \theta_t} = V_s \sum_{\substack{t=1 \\ t \neq s}}^{n} ((-G_{st} \sin(\theta_s - \theta_t) + B_{st} \cos(\theta_s - \theta_t))V_t) \quad \text{...(9)}$$

Neglecting P-V coupling, the relation between incremental change in active power at system buses and the phase angles of voltages can be written in matrix form as

$$[\Delta P] = [H][\Delta \theta]$$

$$[H] = \begin{bmatrix} \frac{\partial P_1}{\partial \theta_1} & \cdots & \frac{\partial P_1}{\partial \theta_n} \\ \vdots & \ddots & \vdots \\ \frac{\partial P_n}{\partial \theta_1} & \cdots & \frac{\partial P_n}{\partial \theta_n} \end{bmatrix}$$

$$[\Delta \theta] = [H]\text{-}1\ [\Delta P] \quad \text{...(10)}$$

$$= [M][\Delta P]$$

$$[M]= [H]-1$$

To find the values of $\frac{\partial \theta_i}{\partial P_{G_g}}$ and $\frac{\partial \theta_j}{\partial P_{G_g}}$, $[M]$ need to be found out. However, is a singular matrix of rank one deficiency. So it is not directly invertible. The slack bus has been considered as the reference node and assigned as bus number 1. The elements of first row and first column of [H]can be eliminated to obtain a matrix $[H_{-1}]$ which can be inverted to obtain matrix $[M_{-1}]$, where $[H_{-1}]$ represents a matrix with its first row and column deleted or a vector with the first element deleted.

Using these relations the following equation can be obtained

$$[\Delta\theta_{-1}]=[M_{-1}][[\Delta P_{-1}] \quad \text{....(11)}$$

The actual vector $[\Delta\theta]$ can be found by simply adding the element $\Delta\theta_1$ to as shown by the following relation

$$[\Delta\theta]= \begin{bmatrix} 0 & 0 \\ 0 & [M_{-1}] \end{bmatrix} [\Delta P]+ \Delta\theta_1[1] \quad \text{...(12)}$$

The second term of the sum in (12) vanishes as $\Delta\theta_1$, being the change in phase angle of slack bus is zero. Accordingly, (12) reduces to

$$[\Delta\theta]= \begin{bmatrix} 0 & 0 \\ 0 & [M_{-1}] \end{bmatrix} [\Delta P] \quad \text{....(13)}$$

Thus required elements of $\frac{\partial \theta_i}{\partial P_{G_g}}$ and $\frac{\partial \theta_j}{\partial P_{G_g}}$ are found out from (13).

It is to be noted that the generator sensitivity values thus obtained are with respect to the slack bus as the reference. So the sensitivity of the slack bus generator to any congested line in the system is always zero.

GS_g denotes how much active power flow over a transmission line connecting bus-i and bus-j would change due to active power injection by generator g. The system operator selects 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.

3. PARTICLE SWARM OPTIMIZATION (PSO)

The Particle Swarm Optimization algorithm (abbreviated as PSO) is a novel population-based stochastic search algorithm and an alternative solution to the complex non-linear optimization problem. The PSO algorithm was first introduced by Dr. Kennedy and Dr. Eberhart in 1995 and its basic idea was originally inspired by simulation of the social behavior of animals such as bird flocking, fish schooling and so on. It is based on the natural process of group communication to share individual knowledge when a group of birds or insects search food or migrate and so forth in a searching space, although all birds or insects do not know where the best position is. But from the nature of the social behavior, if any member can find out a desirable path to go, the rest of the members will follow quickly.

The PSO algorithm basically learned from animal's activity or behavior to solve optimization problems. In PSO, each member of the population is called a particle and the population is called a swarm. Starting with a randomly initialized population and moving in randomly chosen directions, each particle goes through the searching space and remembers the best previous positions of itself and its neighbors. Particles of a swarm communicate good positions to each other as well as dynamically adjust their own position and velocity derived from the best position of all particles.

3.1 The PSO algorithm

The term particle refers to a member of population which is mass less and volume less m dimensional quantity. It can fly from one position to other in m dimensional search space with a velocity. The fitness function in PSO is same as the objective function for an optimization problem.

In real number space, each individual possible solution can be represented as a particle that moves through the problem space. The position of each particle is determined by the vector P_i and its movement by the velocity of the particle v_i given by

$$P_i^{k+1} = P_i^k + v_i^{k+1} \quad \text{…(14)}$$

The information available for each individual is based on

I) its own experience (The decisions it has made so far ,stored in memory)

II) the knowledge of performance of other individuals in its neighborhood.

The relative importance of these two information can vary from one decision to other. A random weight is applied to each part of the information and the velocity is determined as

$$v_i^{k+1} = c_1.r_1\left(P_{best}^k - P_i^k\right) + c_2.r_2(G_{best}^k - P_i^k) \quad \text{…(15)}$$

Where,

P_i^k=position of particle for i^{th} iteration

c_1, c_2= positive acceleration coefficients more than 1.0. Normally its value is taken

Generally $c_1 + c_2 = 4$ or $c_1 = c_2 = 2$.

r_1, r_2= random numbers between 0.0 & 1.0.

P_{best}^k= local best position for i^{th} iteration

G_{best}^k= global best position for i^{th} iteration

Steps in PSO

The PSO method is explained as above. The implementation of the algorithm is indicated below:

1. Initialize the swarm by assigning a random position to each particle in the problem space as evenly as possible.
2. Evaluate the fitness function of each particle.
3. For each individual particle, compare the particle's fitness value with it's P_{best}. If the current value is better than the P_{best} (previous) value, then set this value as the P_{best} and the current particle's position P_i as P_{best} .
4. Identify the particle that has the best fitness value among all particles and corresponding position of the particle as G_{best}.
5. Update the velocity and positions of all the particles using equations.
6. Repeat steps 1 to 5 until a stopping criterion is met (e.g. maximum number of iterations or a sufficient good fitness value).
7. Global best position G_{best} gives the solution of the problem.

4. NUMERICAL STUDY

4. 1 New England 39 Bus System

The 39-bus New England system has been considered for bringing out the effectiveness of the proposed technique. The 39-bus system consists of ten generator buses and 29 load buses. Slack node has been assigned bus number 39. Here line 4-14 is removed to create congestion in the system. Line 6-11 has been found to be congested. Power flow details of congested lines are given in the table

Table 1- Power flow in Congested line of New England 39 Bus System

Sl. No.	From bus	To bus	Power flow (MW)	Line limit (MW)
1.	6	11	495.61	480

The values of generator sensitivities computed for the congested line 2-1 are

Table 2- Generator data of New England 39 Bus System

Sl. No.	Bus	P_g (MW)	P_{max} (MW)	GSF	Generator status
1.	30	250	1040	0	Slack Bus Gen.
2.	31	677.817	700	0.6580	Participating
3.	32	650	725	0.9040	Participating
4.	33	632	652	0.8121	Participating
5.	34	508	508	0.4742	Participating
6.	35	650	687	-0.1067	Not Participating
7.	36	560	580	0.0771	Not Participated
8.	37	540	564	0.1600	Not Participated
9.	38	830	865	0.0771	Not Participated
10.	39	1000	1100	0.0771	Not Participated

The incremental or decrement cost bids of generators are given as

Table 3- Generator cost bids of New England 39 Bus System

Gen No.	30	31	32	33	34	35	36	37	38	39
Cost Bid ($/Mwh)	11	17	19	20	15	10	16	18	17	20

Table 4- Comparison of results for New England 39 bus system

Parameters	Techniques	
	PSO	Result from [16]
Total congestion cost ($/h)	2689	8392.95
Power flow (MW) on line 6-11 after Congestion Management	473.88	476.47

ΔP_{g30} (MW)	91.5	-99.5
ΔP_{g31} (MW)	-28.5	98.75
ΔP_{g32} (MW)	-39.5	-159.64
ΔP_{g33} (MW)	-19	12.34
ΔP_{g34} (MW)	-4.5	24.36
ΔP_{g35} (MW)	Not participated	24.69
ΔP_{g36} (MW)	Not participated	12.34
ΔP_{g37} (MW)	Not participated	24.69
ΔP_{g38} (MW)	Not participated	12.34
ΔP_{g39} (MW)	Not participated	49.34
Total Power Generation Rescheduled (MW)	183	518.45

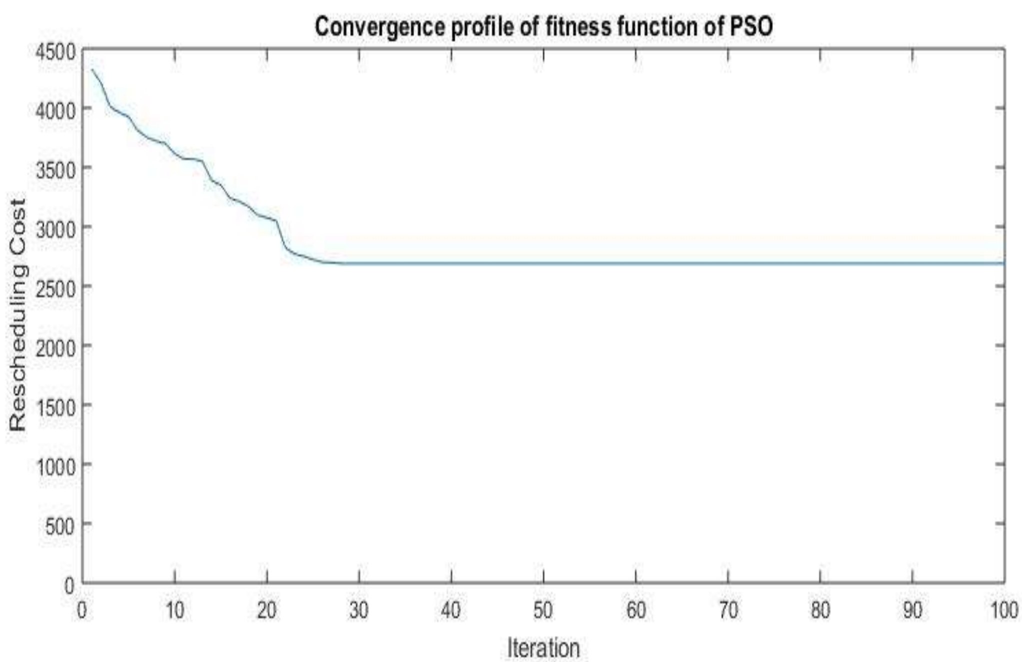

Fig -1 Convergence profile of fitness function of PSO

According to [16], all of the ten generators take part in congestion management. However, based on sensitivity analysis proposed in the present paper (given in Table I), it is apparent that only six of them are sufficient to manage congestion successfully without exceeding the generation limits of generators. The comparative results are tabulated.

From these results, it can be clearly seen that the system losses are lower, voltage profile obtained is better and congestion is managed better as indicated by lower overload factor, by the proposed method.

5. CONCLUSIONS

The present paper focuses on demonstrating a technique for optimum selection of generators for congestion management and additionally the application of PSO in the solution of the congestion management problem. Generators from the system are selected for congestion management based on their sensitivities to the power flow of the congested line followed by corrective rescheduling. The problem of congestion is modeled as an optimization problem and solved by particle swarm optimization technique. The method has been tested on 39-bus New England system successfully. Results obtained on the 39-bus New England system has been compared with the results reported using three other techniques. PSO algorithm has many advantages such as simple concept and easy understanding; the entire complex decision making is modeled by two simple (1) and (2). The robustness of the algorithm is demonstrated by solving three different networks of different sizes and complexities with equal performance. Since the convergence of the PSO algorithm depends on the appropriate selection of particle size, inertia weight and maximum velocity of particles, improper choice of these parameters may lead to inferior results or non-convergence. However, test results reveal that the proposed implementation is effective in managing congestion and outperforms.

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