Congestion Management in Deregulated Power by Rescheduling of Generators

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Abstract – *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.*

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.

Key Words: **Generator sensitivity factor, open power flow, term Transmission Open-Access, Global best position, Local best solution, Particle Position**

1. INTRODUCTION

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.

1.1 Impact of transmission congestion

Market efficiency, in the short term, refers to a market outcome that maximizes the sum of the producer surplus and consumer surplus, which is generally known as social welfare. With respect to generation, market efficiency will result when the most cost-effective generation resources are used to serve the load. The difference in social welfare between a perfect market and a real market is a measure of the efficiency of the real market. The effect of transmission congestion is to create market inefficiency.

Congestion affects virtually each market players either in a positive or in a negative way. At the import side buyer may suffer a decrease in consumer surplus because due to transmission constraints it has limited access of energy from other resources, therefore he has to buy energy from the higher-price seller located at the import side. This lack of choice causes either the higher payment prices or reduced purchases of energy. Therefore, the buyer's consumer surplus decreases. However, a seller located at the import side may offer his output at higher prices, and if the demand is fixed and buyer can afford the price them seller may sell more energy, resulting in an increased producer surplus.

2. PARTICAL SWARM OPTIMIZATION

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.

2.1 Basics of the PSO

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. The next step begins when all particles have been moved. Finally, all particles tend to fly towards better and better positions over the searching process until the swarm move to close to an optimum of the fitness function $f(R^n) \to R$

The PSO method is becoming very popular because of its simplicity of implementation as well as ability to swiftly converge to a good solution. It does not require any gradient information of the function to be optimized and uses only primitive mathematical operators.

As compared with other optimization methods, it is faster, cheaper and more efficient. In addition, there are few parameters to adjust in PSO. That's why PSO is an ideal optimization problem solver in optimization problems. PSO is well suited to solve the non-linear, non-convex, continuous, discrete, integer variable type problems.

2.2 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

$$P_i^{k+1} = P_i^k + v_i^{k+1}$$

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

$$v_i^{k+1} = c_1 . r_1 (P_{best}^k - P_i^k) + c_2 . r_2 (G_{best}^k - P_i^k)$$

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.

3. CONGESTION MANAGEMENT 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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Where n is the number of buses in the system.

Differentiating w.r.t. $\theta_s$andθ_t , the following relations can be obtained:

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

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

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

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

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

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

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

$$[M] = [H]\text{-}1$$

For finding the values of $\frac{\partial \theta_i}{\partial P_{G_g}}$and $\frac{\partial \theta_j}{\partial P_{G_g}}$, [M] need to be find 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

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

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

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

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

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

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.

4. CASE STUDY

The PSO algorithm for congestion management, delineated in the previous sections, has been implemented using Visual C++ programming language. The performance of the algorithm has been studied IEEE 30-bus systems. The performance of the proposed method on IEEE 30-bus has been compared with [15]. While using PSO to solve the congestion problem, algorithm validity and influence of different PSO parameters have also been studied.

4.1 IEEE 30Bus System

The IEEE 30-bus system consists of six generator buses and 24 load buses. Slack node has been assigned bus number 1. Here line 1-3 is removed to create congestion in the system. Two lines have been found to be congested, that are between buses 2 and 1 and that between buses 6 and 2. Power flow details of congested lines are given in the table

The values of generator sensitivities computed for the congested line 2-1 are presented in Table 2.

Table -1: Power flow in Congested line in IEEE 30 Bus System

Sl. No.	From bus	To bus	Power flow (MW)	Line limit (MW)
1.	1	2	170.43	130
2.	2	6	66.24	65

Table -2: Generator data of IEEE 30 Bus System

Sl. No.	Bus	P_g (MW)	P_{max} (MW)	GSF	Status of Gen.
1.	1	184	360.2	0	Slack bus Gen
2.	2	56	140	-0.8623	Participating
3.	5	25	100	-0.9171	Participating
4.	8	15	100	-0.9027	Participating
5.	11	20	100	-0.9171	Participating
6.	13	10	100	-0.9041	Participating

Table -3: Generator cost bids

Gen No.	1	2	5	8	11	13
Cost Bid ($/Mwh)	11	17	19	20	15	10

Table -4: Comparison of results for IEEE 30-bus system

Parameters	Techniques	
	PSO	Method used in [15]
Total congestion cost ($/h)	1483.5	1560
Power flow (MW) on line 1–2 after Congestion Management	111.36	115.42
Power flow (MW) on line 2-6 after Congestion Management	53.89	54.79
ΔP_{g1} (MW)	-54	-58
ΔP_{g2} (MW)	20.5	20.5
ΔP_{g5} (MW)	11.5	14.5
ΔP_{g8} (MW)	6	8
ΔP_{g11} (MW)	8.5	9.2
ΔP_{g13} (MW)	7.5	Not participating
Total Power Generation Rescheduled (MW)	108	110.2

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.

The generator cost curves have been assumed to be quadratic such that cost of rescheduling is proportional to the square of the change in active power output as represented in Table 5.8. Generators selected for participation in congestion management are asked to reschedule their outputs optimally on the basis of their bids so that the cost of rescheduling gets minimized. However the algorithm does not take into account the change of nodal prices or generator bids at pre or post congestion management situation.

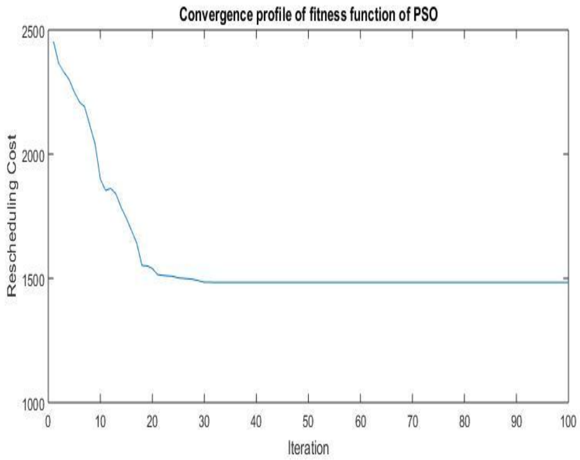

Fig -1: Convergence profile of fitness function of PSO

For comparison purpose, the methodology for generator selection proposed in [15] has been made use of using two different values of MF, which are design variables that regulate the number of generators taking part to be chosen by the operator (as defined in [15]). Generators having positive values of sensitivities are multiplied by their respective bidding values and arranged in a decreasing order according to the resultant product.

Generators having negative sensitivities are divided by their bidding values and arranged in increasing order according to the result. The top entry in each category (positive and negative) multiplied by MF determines the cut-off criteria for generators to be selected. MF varies between 0 to 1, the higher its value, lesser is the number of selected generators.

5. CONCLUSIONS

The present work focuses on demonstrating a technique for optimum selection of generators for congestion management. 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 using Particle Swarm Optimization.
The method has been tested on IEEE 30-bus systems successfully. The result obtained PSO is compared. Both the results are quite satisfactory but Cost of rescheduling is less in case of PSO. Thus it can be said that results obtained from PSO is better . Rescheduling of generators for congestion management is fruitful process as it maintained the supplied quality, security of grid and also taking care of the interest of the consumers without shedding any load.

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