A Novel Method for Generation Rescheduling to Alleviate Line Overloads

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***Abstract*—This paper presents a method for real-time transmission congestion management. Congestion can be alleviated by incorporating line capacity constraints in the dispatch and scheduling process. The objective of this paper is to alleviate the overload and minimize the cost of operation. Here, two objectives congestion and cost are simultaneously minimized. Generation rescheduling of participating generators is done to overcome the congestion. Particle Swarm Optimization (PSO) technique, aims in finding the global optimum of the real-valued function (fitness function) defined in the given space (search space). The technique has been tested on Western System Coordinating Council (WSCC) 3-Machine 9-Bus system and the results are discussed.**

***Index Terms*—congestion, deregulation, ISO, OPF, PSO**

NOMENCLATURE

NL	Number of overloaded lines;
S_i	MVA flow on line *i*;
S_{cap}	MVA capacity of line *i*;
NG	Number of participating generators;
a_i, b_i, c_i	Cost coefficients of generator *i*;
P_{Gi}, Q_{Gi}	Real and reactive power generation at i^{th} bus;
P_{Di}, Q_{Di}	Real and reactive power demand at i^{th} bus;
NB	Number of buses;
Y_{ii}	Self–admittance of node *i*;
Y_{ij}	Mutual admittance between node *i* and *j*;
δ_i, δ_j	bus voltage angle of bus *i* and bus *j*, respectively;
θ_{ij}	Impedance angle of line between buses *i* and *j*;
$P_{Gi}^{min}, P_{Gi}^{max}$	minimum and maximum active power generation limits at bus *i*;
$Q_{Gi}^{min}, Q_{Gi}^{max}$	minimum and maximum reactive power generation limits at bus *i*;
V_i^{min}, V_i^{max}	minimum and maximum voltage limits at bus *i*;

I. INTRODUCTION

Restructuring of electric supply sector is taking place all over the world. The restructuring and deregulation of the power system has significantly changed the function of power system resulting in significant competitive, technological and regulatory changes [1]. In Asian countries such as India, China and Thailand the restructuring is underway with different objectives followed by Britain, Spain, New Zealand, Argentina, Chile, Norway and Sweden [2]. Congestion was present in power systems before deregulation and was discussed in terms of steady state security. Its basic objective was to control generator output so that the system remains secure (no limits violated), at the lower cost. Most of the energy sales were between adjacent utilities and a transaction would not go forward unless each utility agreed that it was in their best interest for both economy and security. Problems like the one we call congestion would only arise when the transaction had an impact in the security of a utility not involved in the transaction (third party wheeling). Congestion is a new term (in power systems) that comes from economics. It is being used after restructuring, for designing situations in which producers and consumers desire to generate and consume electric power in amounts that would cause the transmission system to operate at or beyond one or more of its transfer limits. Congestion management consists of controlling the transmission system so that the transfer limits are observed. Therefore, congestion management is one of the key functions of any system operator (SO) in the restructured power industry. The basic principle and method when ISO deals with the congestion in the emerging energy market are discussed in [3]. A Primal-dual Interior Point Linear Programming method is applied to solve congestion model in [4]. This method can be used to solve real-time congestion. Optimal power flow (OPF) is arguably the most significant technique for congestion management in a power system with existing transmission and operational constraints [5]. Congestion

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is dependent to the network constraints that may show the ultimate transmission capacity, while it can restrict the concurrent electric power contracts [6]. Congestion managements applied in various kinds of electricity market are evaluated in [7], and a numerical example is utilized to manifest the principle involved. Many methods have been proposed in the literatures for determining a secure operating point. Non-linear programming methods have been introduced for finding the coordinated control actions to eliminate the line overloads [8], [9]. In [10], a direct method for generation rescheduling and load shedding to alleviate line overloads is proposed. In this method, bus powers are modified appropriately only at the terminal buses of the overloaded line, by an amount equal to the line overload during each iteration of the load flow solution. A hit and miss method has been developed rather than developing a basis to calculate the correct bus power adjustments. Hence, the process is quite time consuming. There are two broad paradigms that may be employed for congestion management. They are the *cost-free* means and the *not-cost-free* means. The former include actions like outaging of congested lines or operation of transformer taps, phase shifters, or FACTS devices. These means are termed as *cost-free* only because the marginal costs (and not the capital costs) involved in their usage are nominal.

The not-cost-free means include:

- Re-dispatching the generation amounts. By using this method, some generators back down while others increase their output. The effect of re-dispatching is that generators no longer operate at equal incremental costs.
- Curtailment of loads and the exercise of load interruption options.

It is desirable that, a new secure operating point is obtained with minimum control action in less time. In recent years, PSO's [11], [12] are gaining popularity for their easy searching process, global optimality, probabilistic nature and robustness, enabling one set of general control parameters to solve a wide range of problems. In this paper, a PSO based solution to the modified OPF is proposed for corrective rescheduling with line flow constraints.

II. Problem Formulation

The objective of congestion management is to alleviate the overload and minimize the cost of generation. Mathematically, this can be represented as in the following.

Objective 1

$$Min\sum_{i=1}^{NL} S_i - S_{cap} \tag{1}$$

Objective 2

$$Min\sum_{i=1}^{NG}(c_i + b_i\, P_{Gi} + a_i P_{Gi}{}^2) \tag{2}$$

Subjected to:

Equality Constraints:

$$P_{Gi} - P_{Di} = \sum_{j=1}^{NB} |V_i||V_j||Y_{ij}|\cos(\delta_i - \delta_j - \theta_{ij}) \tag{3}$$

$$Q_{Gi} - Q_{Di} = \sum_{j=1}^{NB} |V_i||V_j||Y_{ij}|\sin(\delta_i - \delta_j - \theta_{ij}) \tag{4}$$

Inequality Constraints:

$$P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max} \tag{5}$$

$$Q_{Gi}^{\min} \le Q_{Gi} \le Q_{Gi}^{\max} \tag{6}$$

$$V_i^{\min} \le V_i \le V_i^{\max} \tag{7}$$

III. Overview of PSO

PSO technique is similar to evolutionary algorithm in which searching is done using a population of particles, corresponding to individuals. PSO is introduced by Kennedy and Eberhart in the year 1955. PSO has potential solution called particles fly through the problem space by following the current optimum particles. PSO is a global optimization algorithm for dealing with problems in which a best solution can be represented as a point in n-dimensional search space. PSO is a population based searching method having individuals called particles which can change their position relative to the time. PSO has a flexible and well-balanced mechanism to enhance and adapt to the global and local exploration abilities. Each particle adjusts its position according to its own experience known as cognitive parameter and according to experience of neighboring particle as social parameter.

Each particle tracks its coordinates in the two dimensional problem space in which particles are associated with the best solution so far achieved. This value is called P_{best}. When a particle takes all the population as its topological neighbors, the best value among P_{best} is a global best and is called g_{best}. Each particle represents a potential solution to an optimization problem. Let, x is the particle position and v is its speed in search space. The population size is p. The population of particle is $X^i\ (X^1, X^2 \ldots X^p)$ for each particle, the position of particles can be updated as,

$$x^i{}_{k+1} = x^i{}_k + v^i{}_{k+1} \tag{8}$$

Using the global best and individual best of particle j^{th} velocity of particle in k^{th} dimension is updated as,

$$v^i{}_{k+1} = w_k v^i{}_k + c_1 r_1 (p^i{}_k - x^i{}_k) + c_2 r_2 (p^g{}_k - x^i{}_k) \tag{9}$$

where

$v^i{}_{k+1}$ Particle's new velocity

$v^i{}_k$ Particle's previous velocity

$p^i{}_k$ The past best position of particle *i* at time *k*

$p^g{}_k$ The past global best position in the swarm at time *k*

x_k^i Particle i's position at time k

x_{k+1}^i Particles new position

w_k Inertia weight

c_1, c_2 Acceleration constant

r_1, r_2 Uniform random numbers between 0 and 1

Here, the subscript k indicates pseudo-time increment. Within the boundary $0 \le V_0 \le V^{max}$, the maximum Velocity V^{max} allowed serving as a constraint that controls the maximum global exploration. The performance of each particle is measured according to the pre-determined fitness function. Each particle moves around the search space updating its velocity and position based on the best positions so far discovered by it and other particles. The inertia weight w_k is used to control the impact of previous velocity on current velocity and to influence the trade-off between local and global exploration of particles. In equation (9), the first term indicates the current velocity of the particle, second term represents cognitive part and third term represents the social part of PSO. c_1 and c_2 are known as cognitive and social parameters.

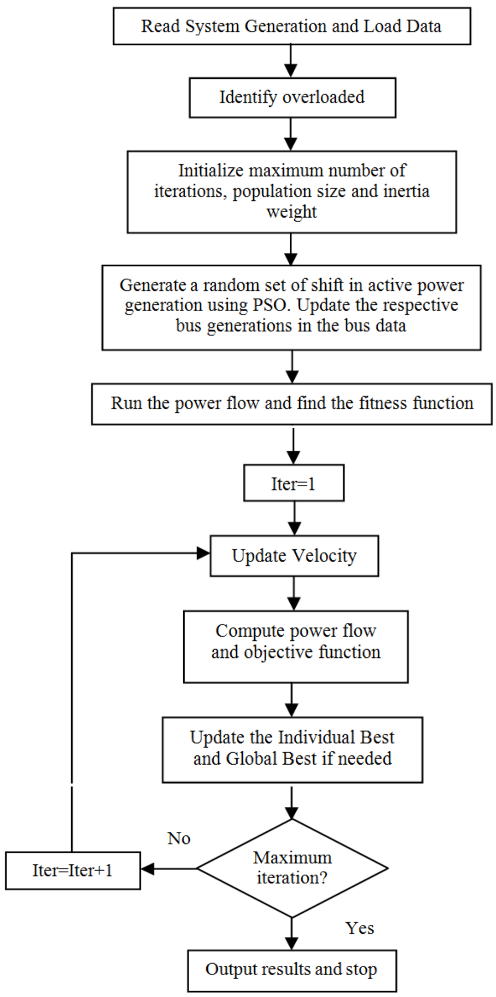

Figure 1. Flowchart for the proposed algorithm

IV. Implementation Using PSO

In PSO algorithm, the population has p number of particles and each particle is a k-dimensional vector where k is the number of optimized parameter. Incorporating the above modifications, the computational flow of PSO technique can be described in the following steps.

Step 1 Read the system load and generation data.

Step 2 Conduct load flow using N-R method.

Step 3 Check the Real & Reactive power limits and also the voltage limits.

Step 4 Identify the overloaded lines and set the flag value.

Step 5 Select the PSO control parameters, population size and iteration number.

Step 6 Randomly generate Active power for each particle.

Step 7 Check whether the active power values are within limits.

Step 8 Produce a set of optimal solution using PSO.

Step 9 If overload is alleviated, provide the solution to the operator and also find the corresponding fuel cost, goto 10.

Step 10 Output the best generation pattern and stop.

The flowchart for the proposed work is shown in Fig. 1.

V. Results and Discussion

A. System Description

The proposed framework is applied to the WSCC 3-Machine 9-Bus system. The system is documented in Power System Control and Stability by Anderson and Fouad. The system includes three generator and three large equivalent loads connected in a meshed transmission network through transmission lines as shown in Fig. 2. The generator is connected at buses 1, 2 and 3. For this system, bus 1 is a slack bus.

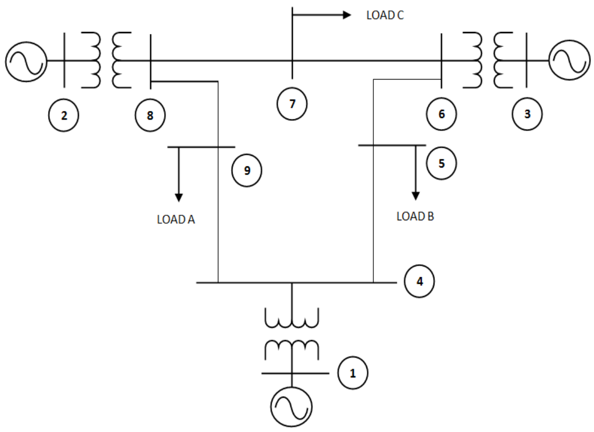

Figure 2. WSCC 3-machine 9-bus system

B. Design of Cases for Analysis

In this work we consider only bilateral transaction since it is the most common transaction types in deregulated environments. The line flow capacity constraints remain the same for initial and emergency cases. A bilateral transaction is simulated by making transfer from the generator at bus 2 to load at bus 5. The total fuel cost and the generation pattern for the base case are shown in Table I.

TABLE I. GENERATION PATTERN FOR THE BASE CASE

Total power demand (MW)		315
Power Generated (MW)	P1	71.89
	P2	163
	P3	85
Total Power Loss (MW)		4.89
Total Fuel Cost ($/hr)		5436.97

For the given generation, load pattern and transaction the power flow for the system shows that, overload occurs on lines 1-4 and 6-7 (Table II). The aim is to minimize the rescheduling of generation required to limit the flow on lines 1-4 and 6-7. Proposed algorithm is run for rescheduling of generation. Table III shows the generation pattern before and after corrective rescheduling. Simulation is carried out by taking the values of PSO parameters as:

- Inertia weight in the range of 0.4 to 0.9
- Acceleration constant c_1, c_2 as 1.
- Population size as 5
- Number of iteration 50

TABLE II. LINE FLOWS FOR TRANSACTION FROM BUS 2 TO 5 BEFORE RESCHEDULING

Line no	From-To Bus	Line flow Limits (MVA)	Actual Power flow (MVA)	Power Overflow (MVA)
1	**1-4**	**250**	**293.61**	**43.61**
2	4-5	250	113.12	0
3	5-6	150	1.17	0
4	3-6	300	106.25	0
5	**6-7**	**150**	**164.98**	**14.98**
6	7-8	250	21.09	0
7	8-2	250	0	0
8	8-9	250	21.14	0
9	9-4	250	177.74	0

TABLE III. GENERATION PATTERN BEFORE AND AFTER RESCHEDULING

Bus No.	Generation (MW)	
	Before Rescheduling	After Rescheduling using PSO
1	79.89	184.56
2	263	104
3	85	134.54
Total Power Loss (MW)	8.89	8.10
Total Fuel Cost ($/hr)	9177.94	9150.73

The results from PSO shows that, bus 1 must increase its generation by 104.67MW, bus 2 must drop its generation by 159MW and bus 3 must increase its generation by 49.54MW. It is clear that the total fuel cost after rescheduling is less compared with the total fuel cost before rescheduling. Table IV shows the line flows for transaction from bus 2 to 5 after rescheduling obtained by using PSO.

TABLE IV. LINE FLOWS FOR TRANSACTION FROM BUS 2 TO 5 AFTER RESCHEDULING

Line no	From-To Bus	Line flow Limits (MVA)	Actual Power flow (MVA)	Power Overflow (MVA)
1	1-4	250	230.70	0
2	4-5	250	74.66	0
3	5-6	150	38.62	0
4	3-6	300	168.17	0
5	6-7	150	129.05	0
6	7-8	250	2.44	0
7	8-2	250	0	0
8	8-9	250	2.41	0
9	9-4	250	153.98	0

It is evident from Table IV that the power flows in all the lines are within limits after rescheduling. There was no violation of power balance constraint.

VI. CONCLUSION

The problem of generation rescheduling for alleviation of line overloads is very important for operational planning, security studies and reliability evaluation of power systems. An efficient, reliable and direct method is always desirable. The proposed method could specifically eliminate congestion in transmission grids using cost-efficient generation rescheduling. A realistic frequency and voltage dependent modified Newton Raphson load flow method is used with PSO technique to solve this complex problem. A market for Bilateral Transactions has been designed. The results of case studies have shown that, this scheme would be very effective in handling wheeling transactions. The proposed model performed efficiently with 9 bus test system and the same can be extended to any practical network. The proposed model is mainly free from complex mathematical formulation and provides quite encouraging results and the obtained results are found to be useful for all feasible transactions in deregulated environment. It is clearly established that, the proposed method gives a new secure operating state with significantly less shift in generation, with a little deviation from the pre-adjustment state. The proposed method will be an aid to the load dispatcher.

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