Congestion Influence on Optimal Bidding in a Competitive Electricity Market using Particle Swarm Optimization

J Vijaya Kumar[1], Shaik Jameer Pasha[2], D.M.Vinod Kumar[3]
Department of Electrical Engineering, National Institute of Technology Warangal, India.
E-mail: jvkeee@gmail.com

Received: July 2010 Revised: August 2010 Accepted: September 2010

ABSTRACT:
Electricity market plays an important role in improving the economics of electrical power system. Transmission network is vital entity in an open access restructured electricity market. Whenever transmission network congestion occurs in an electricity market, it divides the market in different zones and the trading price of electricity will no longer remains the same for the whole system. Bidding strategies in an electricity market, where by changing the bid, market player changes the revenue of every participant of the market. In this paper, the bidding strategy problem with congestion management is modeled as an optimization problem and solved using Particle Swarm Optimization (PSO). Search procedure of PSO is based on the concept of combined effect of cognitive and social learning of the members in a group. The effectiveness of the proposed method is tested with a numerical example and the results are compared with Genetic Algorithm (GA) approach. The results shows that PSO takes less computational time and maximizing the social welfare compared to GA approach.

KEYWORDS: Bidding Strategy, Congestion Management, Particle Swarm Optimization (PSO).

1. INTRODUCTION

The success of privatization of most of the industries led people to think for the restructuring of electric power system. This yields to restructuring of currently Vertically Integrated Utility (VIU) to the main three utilities, namely Generation Company (GENCOs), Transmission Company (TRANSCOs) and Distribution Company (DISCOs). The success in the energy privatization in the countries like UK, USA, Norway and Australia has encouraged many more countries to privatize their electricity industry. India has also participated in the process and most of the states of India have restructured their electricity boards. Ever since the restructuring has taken place, the electric power industry has seen tremendous changes in its operation and governance. Electricity, being a concurrent entity, cannot be stored easily. This emphasizes on generation and consumption of electricity at the same time. Ascertain of electricity market gave new dimension on power system engineer and the economics of power system.

The sole purpose of introduction of restructuring of electrical power system and electricity market is to create a healthy competition among the participant of the market and to make electricity market more efficient, liquid and complete. The fundamental objectives behind the establishment of electricity market are the secure operation of power system and facilitating an economic operation of the system. Key entities of the electricity market are Generating Companies (GENCOs),

Independent System Operator (ISO), Transmission Companies (TRANSCOs) and Distribution Companies (DISCOs) [1]. The development of electricity market also aims for the maximum participation from the electric utilities to provide transparent and non-discriminatory platform for energy producers. Whenever the network component is overloaded the network is called congested network. The efficiency of the electricity market decreases in the event of transmission line congestion. The congestion results in price change and reduces the market efficiency. Congestion can be managed by different approaches. One of the approaches is real and reactive power rescheduling [2]. Strategic bidding is the gaming of players of the market by which the players in the market submits bid to accomplish maximum benefit [3].

Ferrero [4] proposed Game Theory based bidding method. Weber and Zhang [5, 6] proposed optimization based bidding strategies. Richter [7] proposed comprehensive bidding strategies with GA. Strategic bidding problem has been formulated as a two level optimization problem [8–12], in which producers try to maximize their profit based on the market clearing price (or bid price), and dispatch quantity is obtained from an optimal power flow model. Using deterministic approach, it is difficult to obtain the global solution of such bi-level optimization problem because of nonconvex objective functions and non-linear complementarity conditions [8, 9] to represent market clearing. These difficulties are avoided by representing the residual demand function by mixed integer linear programming (MILP) model [10, 11], in which unit commitment and uncertainties are also taken into account. In [12], the generators associated to the competitors' firms have been explicitly modeled as an alternative MILP formulation based on a binary expansion of the decision variables (price and quantity bids).

In general, strategic bidding is an optimization problem that can be solved by various conventional and non-conventional (heuristic) methods. Depending on the bidding models, non-differentiable optimization is well established area of the mathematical optimization field with well known conventional, non-heuristic methods. Heuristic methods such as GA, Simulated Annealing (SA) and Evolutionary Programming (EP), Particle Swarm Optimization (PSO) etc, have main limitations of their sensitivity to the choice of parameters, such as the crossover and mutation probabilities in GA, temperature in SA, scaling factor in EP, inertia weight, learning factors in PSO. The major difference between PSO and other evolutionary algorithms is that, in PSO, the particles remain the same, but their characteristic (position and velocity) change, with new individual being 'generated' in each iteration. The GA typically requires three major operators: selection, crossover, mutation. In the PSO, however, there is one simple operator: velocity calculation. The advantage of dealing with one operator is the reduction of computation and elimination of the process to select the best operator for a given optimization.

In this paper, the single sided bidding is considered, where only suppliers will participate in the bidding process. Congestion has been intentionally created in the system to analyze profit, with and without congestion, and to develop strategic bidding accordingly. Particle Swarm Optimization (PSO), along with dc sensitivity factors to include congestion management, has been used to decide optimal bidding strategy to maximize the profit of the suppliers. The profit's deviations of congestion's influence for all participants are analyzed in detail. Numerical analysis will clarify congestion's influence on price and bidding strategy. The result shows that PSO technique can generate better quality solution within shorter calculation time and stable convergence characteristic compared to GA.

2. ELECTRICITY MARKET ARCHITECTURE

The electricity market architecture comprises of main four entities namely GENCOs, TRANSOs, DISCOs and an Independent System Operator (ISO). GENCO is not necessary to have its own generating plants, but it can negotiate on behalf of generating companies. In ancillary market GENCO has opportunity to sell its reserves and reactive power. The GENCO will try to maximize its own profit, whatever way it can, by selling the power in the market. TRANSCO transmit the power from power producer to power consumer. It also maintains the transmission system to increase overall reliability of power system. DISCO distributes the power to retail companies, brokers or to its own consumers. ISO is an independent body which maintains the instantaneous power balance in the system. ISO is also responsible for secure operation of the grid. There could be two types of ISO, one is known as MinISO and the other is MaxISO [1]. While MinISO, looking after the grid security and has no role in power market, MaxISO model includes Power Exchange (PX). The function of PX is to provide a competitive market place for all the participant of the market. ISO uses the assets of TRANSCO for its functioning. The role of ISO also encompasses the fare use of transmission network, maximizing social welfare of the market, running PX, and maintaining grid security and to run separate market for ancillary services.

The ISO or PX accepts bids from all the players of the market and determines the Market Clearing Price (MCP), where MCP is the intersecting point of supply curve and demand curve as shown in Fig. 1. Whenever there is no network congestion, MCP is the only one price for every node of the system. But because of the congestion the whole system is being segregated in different zones and zonal market clearing price is used for different zones.

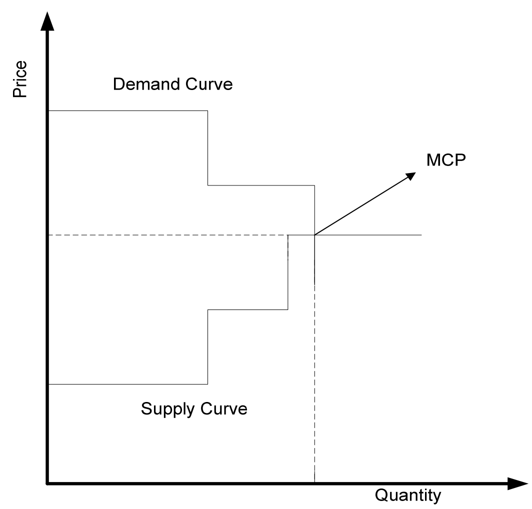

Fig. 1. Market Equilibrium Point

3. NETWORK CONGESTION

Whenever the network component is overloaded the network is called congested network. In an electricity market, when the bidding process is over, ISO analyze the power system security. In a competitive market, network congestion has its own importance because of the complexity involved. This congestion may be due to overloading of transmission line or transformer. The problem of network congestion can be alleviated with the help of phase shifter, tap changing transformers and curtailment of loads. It can also be solved by removing the overloaded component from the system. But this might aggregate the network congestion.

4. MODEL OF BIDDING STRATEGY

4.1 Bidding strategy without line flow constraints

The bidding problem consists of price offers and the amount of loads to be satisfied in the competitive market. The bid price curves for generators and customers are quadratic convex and concave functions, respectively. All participants submit a bidding strategy to maximize the social welfare while satisfying various constraints. The model of bidding strategy without line flow constraints can be first formulated as

$$Max.\ Obj\ \ f_k = \sum_{i=1}^{NL} B_i(d_i) - \sum_{j=1}^{NG} C_j(p_j) \tag{1}$$

With $B_i(d_i) = b_i d_i^t - \frac{1}{2} q_{ii}(d_i^t)^2$

$$C_j(p_j) = b_j p_j^t + \frac{1}{2} q_{jj}(p_j^t)^2$$

$$s.t \quad \sum_{j=1}^{NG} p_j = \sum_{i=1}^{NL} d_i \tag{2}$$

$$p_j^{\min} \le p_j \le p_j^{\max} \tag{3}$$

where,

i, j : generator and customer index

NL: the number of customers

NG: the number of generators

C_j : the cost (or bid) function of generator j

B_i : the benefit function of customer i

P_j : bid quantities of generator j

d_j : bid quantities of customer j

p_j^{min}, p_j^{max} : the lower and upper generation output

4.2 The regulation of bidding strategy by congestion

When the congestion occurs after the bidding process, suppliers will regulate the power output to meet the security constraints. In this paper, a DC load flow model is used and transmission line loss is neglected. The curtailment algorithm can be formulated as

$$\underset{\Delta p_i}{Min}\, \Delta P^T W \Delta P \tag{4}$$

$$|P_{ij}| \le |P_{ij}|^{\max} \tag{5}$$

$$\sum_{i\varepsilon G} \Delta P_i = 0 \tag{6}$$

where $\Delta P = [\Delta P_1, \Delta P_2 \ldots\ldots\ldots \Delta P_n]$ is the vector of the supplier's curtailment. ΔP_i is the increased/decreased output of generator i. If $\Delta P_i>0$, i^{th} supplier must increase its output. P_{ij} denotes the line flow. W, which is a diagonal weight matrix, is set to 1 in this paper. Either increasing output or decreasing output, the curtailed power must sum up to 0 such as (6). It is clear that the curtailed power will result in the lost profits of suppliers and their cost must be allocated among market participants. Thus, the new bidding strategy will re-formulated as

$$Max.\ ECP \times (P^* + \Delta P_i) - C_i(P_i + \Delta P_i) + REG_{cost} \tag{7}$$

$$s.t \quad \sum_{j=1}^{NG} p_j = \sum_{i=1}^{NL} d_i \tag{8}$$

$$p_j^{\min} \le p_j \le p_j^{\max} \tag{9}$$

$$|p_{ij}| \le |p_{ij}|^{\max} \tag{10}$$

$$\sum_{i\varepsilon G} \Delta p_i = 0 \tag{11}$$

REG_{cost} is the regulated cost for generators. It can be found as:

$REG_{cost} = - \Delta P_i \times (ECP - Bi(P_i + \Delta P_i))$.

5. SOLUTION ALGORITHM

The PSO method is a self-educating optimization algorithm that can be applied to any nonlinear optimization problem [13]. In PSO, the potential solutions, called particles, fly through the problem space by following the best fitness of the particles. It exhibits some evolutionary computation attributes such as initialization with a population of random solutions and search for optima by updating generations. PSO seems to be sensitive in tuning of parameters and many researchers [14-16] are still in progress in regulating these to improve the performance.

The updates of particles are accomplished according to the following equations. Equation (12) calculates a new velocity for each particle r, based on its previous velocity (V_r^K), the particle's location at which the best fitness has been achieved ($P_{best\ r}$) so far, and the best particle among the neighbors (G_{best}) at which the best fitness has been achieved so far. The learning factors a_1 and a_2 are the acceleration constants that change the velocity of a particle towards $P_{best\ r}$ and G_{best}, and $rand_1$, $rand_2$ are uniformly distributed random numbers in [0, 1]. Each particle's position is updated using (13) in the solution hyperspace. It is concluded that the PSO with a linearly decreasing (LD) inertia weight W^k in each iteration k, from maximum value W_{max} to minimum value W_{min}, as reflected in (14) can make a significant improvement on convergence to the global optimum within a reasonable number of iterations [17].

$$V_r^{k+1} = w^k V_r^k + a_1 rand_1 * \left(P_{best}^k - X_r^k\right) + a_2 rand_2 * \left(G_{best}^k - X_r^k\right) \quad (12)$$

$$X_r^{k+1} = X_r^k + V_r^{k+1} \quad (13)$$

$$w^k = w_{\max} - \frac{w_{\max} - w_{\min}}{k_{\max}} * k \quad (14)$$

where k is the iteration counter and k_{max} is the maximum iteration number.

The velocity update expression (12) can be explained as follows [18]. Without the second and third terms, the first term (representing inertia) will keep a particle flying in the same direction until it hits the boundary. Therefore the first term tries to explore new areas and corresponds to the diversification in the search procedure. In contrast, without the first term, the velocity of the flying particle is only determined by using its current position and its best positions in history. Therefore the second (representing memory) and third terms (representing cooperation) try to converge the particles to their $P_{best\ r}$ and/or G_{best} and correspond to the intensification in the search procedure. Namely, the PSO has a well-balanced mechanism to utilize the diversification and the intensification in the search procedure efficiently. The flow chart for the proposed PSO is shown in Fig. 2

5.1 PSO algorithm for bidding problem

The computational steps in optimal strategy searching process using PSO algorithm are described below

Step1. Read line data, generator cost coefficients and generation limits for each unit.
Step2. Initialize the particles (strategic variable) of population randomly. These initial particles must satisfy the constraints of (8) and (9).
Step3. Calculate the fitness value of each particle in the population using fitness function (7)
Step4. Each P_{best} values are compared with the other P_{best} values in the population. The best evaluation value among the P_{best} is denoted as G_{best}
Step5. Update the iteration counter; $k=k+1$
Step6. Update the inertia weight w using (14) and modify the velocity and position of each particle using (12) and (13), respectively. If a particle violates its position limits in any dimension, set its position at proper limit.
Step7. If the iteration counter reaches predefined maximum iteration k_{max}, then Stop; else go to step 4.
Step8. The particle that generates the latest G_{best} is the optimal value.

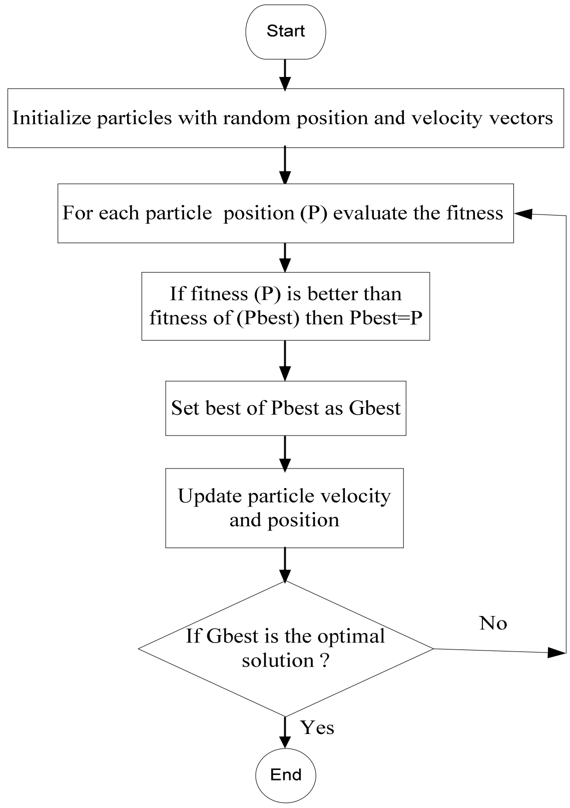

Fig. 2. Flowchart of the proposed PSO method

PSO uses random initialization, but it gives almost the same optimal solution in asset of simulations within a given case. It shows its immunity to the start point. The number maximum iterations required to obtain the global solution is dependent on the nature and size of the problem. The system has been solved for DC power flow and the loading of the lines is calculated. Fig 3 explains the bidding procedure with congestion management.

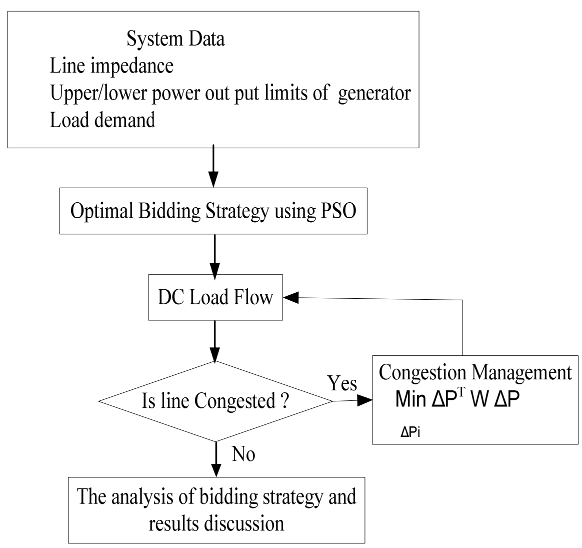

Fig. 3. Flowchart of the bidding approach

6. CASE STUDY

To illustrate the bidding strategy with congestion, a 5-bus power system with three generators and two customers are interconnected by six transmission lines is shown in Fig. 4. The bid data for generators and customers are given in Table1. The transmission line without congestion is considered in order to analyze the congestion influence on the bidding strategy and price. The bid quantities and cost for participants are allocated by using proposed PSO method shown in Table 2. From the Table 2, it observed that the social welfare using PSO is more compared to GA without considering congestion of the transmission line network.

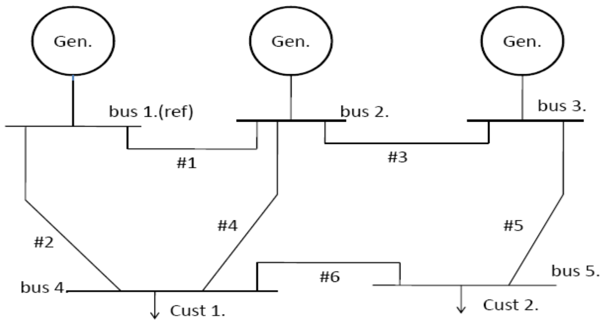

Fig. 4. Five bus Power system

Table 1. The Bids Data for Participants

Generator	Cost function ($)	P^{min}	P^{max}
Gen.1	$560+7.92P_1+0.001562P_1^2$	0(MW)	200(MW)
Gen.2	$310+7.85P_2+0.00194P_2^2$	0(MW)	150(MW)
Gen.3	$78+7.97P_3+0.004822P_3^2$	0(MW)	150(MW)
Customer	Profit function ($)	Peak load	
Cust.1	$100d_1- 0.175d_1^2$	200(MW)	
Cust.2	$110d_2 – 0.15d_2^2$	150(MW)	

Table 2. The Social Welfare without Congestion

	PSO		GA	
Generator	Output (MW)	Cost ($)	Output (MW)	Cost ($)
Gen.1	153.65	1813.78	158.299	1852.87
Gen.2	141.75	1461.74	145.497	1493.22
Gen.3	44.58	442.94	46.0936	455.611
Total cost for Generators	3718.46		3801.701	
Customer	Load (MW)	Cost ($)	Load (MW)	Cost ($)
Cust.1	200	14184.87	200	14184.74
Cust.2	150	20049.01	150	20048.84
Total benefit for customers	34233.88		34233.58	
Social welfare ($)	30515.420		30475.173	

Table 3 shows the line flow before and after congestion management. From the Table 3, line #4 violates the flow limit after bidding strategy and it is regulated from 253.30MW to 246.07MW after congestion management.

Table 3. Line flow before and after congestion management

Line No.	Line flow after bidding strategy	Line limits	Line flow after congestion management (MW)
#1	173.65	250	156.50
#2	23.91	250	23.09
#3	-46.82	250	-55.73
#4	253.30	250	246.07
#5	72.80	250	80.82
#6	77.20	250	69.177

Due to the line #4 is overload after bidding strategy; ISO has to curtail the power in order to keep the security operation. The simulation results are summarized in Table 4. Gen.2 curtails the output from 141.75 MW to 31.206 MW and the lost profit is $904.884. Similarly, Gen.1 and Gen.3 increase the output for meeting the load demand. The social welfare after congestion management using PSO is $30388.420, which is more than the social welfare obtained by using GA.

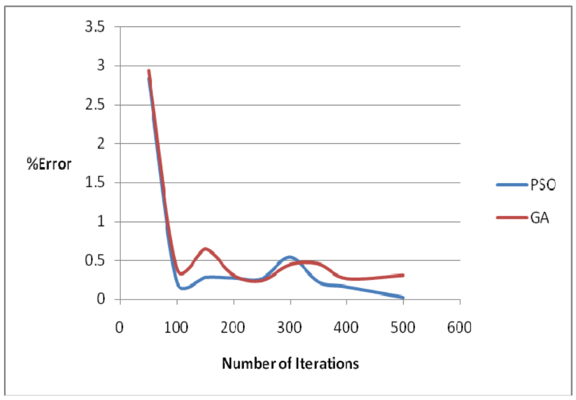

Fig. 5. The convergence characteristics of PSO and GA

From the results it is found that, due to congestion in transmission system, suppliers can increase their profit through strategic bidding, but the overall social benefit is decreasing. Fig.5 illustrates the convergence characteristics of PSO and GA. The c. p. u time taken for 600 generations using PSO is 0.074 sec, where as GA takes 0.1190 sec. This shows the robustness and effectiveness of the proposed method. The parameters used for PSO and GA as follows: No. of particles: 200, Maximum number of Iterations: 1000, $a1=a2=2.0$, $w=0.9$ to 0.4 for PSO and Population size: 200, Maximum Iterations: 1000, elitism: 0.15, mutation: 0.05 and crossover: 0.85 for GA.

Table 4. The simulation results

	PSO			GA		
	Gen.1	Gen.2	Gen.3	Gen.1	Gen.2	Gen.3
Output without congestion management (MW)	153.65	141.75	44.58	158.29	145.49	46.09
Output with congestion management (MW)	185.26	31.20	130.78	186.83	32.10	131.54
Curtailed Output (MW)	31.61	-110.55	86.2	28.53	-113.39	85.44
Gain/Lost Profit($)	267.09	-904.88	759.81	374.37	-897.32	796.79
Total cost for Generators ($)	3840.1878			4075.542		
Total Benefit for Customers ($)	34233.58			34233.58		
Social welfare ($)	30388.39			30158.038		

7. CONCLUSIONS

In this paper, application of PSO for bidding strategy with congestion is proposed. In this approach, each participant tries to maximize their profit with the help of information announced by ISO. The curtailment decisions are performed to keep system operation within security limits. Numerical analysis will clarify congestion's influence on price and bidding strategy. The profit deviations of congestion influence for all participants are analyzed in detail. From the results it can be conclude that, congestion of any transmission line will reduce the social welfare. The results are compared with GA. The numerical results reveal the superiority of the proposed PSO compared to GA with respect to social welfare and convergence of c. p. u time. Therefore, the proposed algorithm produces maximum social welfare and converges rapidly.

REFERENCES

[1] M. Shahidehpour, H. Yamin, Z. Li, **"Market Operation in Electric Power Systems"**, *Forecasting,Scheduling and Risk management*,John Wiely Sons, 2002.

[2] A Kumar, S C Shrivastava, S N Singh, **"A Zonal Congestion Management Approach Using Real and Reactive Power Rescheduling"** *IEEE Transaction on Power Systems,* Vol 19, No. 01, Feb 2004

[3] Loi Lai Lei Power System Restructuring and Deregulation, (Edited), John Wiley & Sons Limited, 2001.

[4] R. W. Ferrero, S. M. Shahidehpour, and V. C. Ramesh, **"Transaction analysis in deregulated power system using game theory,"** *IEEE Trans.on Power Systems*, Vol. 12, no. 3, pp. 1340–1347, August 1997.

[5] J. D. Weber and T. J. Overbye, **"A two-level optimization problem for analysis of market bidding strategies,"** *in Proceedings of IEEE Power Engineering Society 1999 Summer Meeting*, 1999, pp.682–687.

[6] D. Zhang, Y. Wang, and P. B. Luh, **"Optimization based bidding strategies in the deregulated market,"** *in Proceedings of IEEE PES 21st Power Industry Computer Applications Conference (PICA'99)*, 1999,pp. 63–69.

[7] C. W. Richter, G. B. Sheble, and D. Ashlock, **"Comprehensive bidding strategies with genetic programming/finite state automata,"** *IEEE Trans. on Power Systems,* Vol. 14, no. 4, pp. 1207–1212, 1999.

[8] B.F., Metzler, C.B., and Pang, J.S.: **"Strategy gaming analysis for electric power systems: an MPEC approach"**, *IEEE Trans. Power Syst*., 2000, 15, (2), pp. 638–645

[9] Hobbs, B.F., and Helman, U.: **"Complementarity-based equilibrium modeling for electric power markets' in Bunn, D. (Ed.): 'Modeling prices in competitive electricity markets"** (Wiley, New York, 2004)

[10] Baillo, A., Ventosa, M., Rivier, M., and Ramos, A.: **"Optimal offering strategies for generation companies operating in electricity spot markets"**, *IEEE Trans. Power Syst.,* 2004, 19, (2), pp. 745–753.

[11] Torre, S., Arroyo, J.M., Conejo, A.J., and Contreras, J.: **"Price maker self-scheduling in a pool-based electricity market: a mixed-integer LP approach,"** *IEEE Trans. Power Syst.*, 2002, 17, (4), pp. 1037–1042.

[12] Pereira, M.V., Granville, S., Fampa, M., Dix, R., and Barroso, L.A.: **"Strategic bidding under uncertainty: a binary expansion approach, "** *IEEE Trans. Power Syst.*, 2005, 20, (1), pp. 180–188.

[13] Kennedy, J., and Eberhart, R.: **"Particle swarm optimisation, "** *Proc.IEEE Int. Conf. Neural Networks*, 1995, vol. 4, pp. 1942–1948.

[14] Parsopoulos, K.E., and Vrahatis, M.N.: **"Recent approaches to global optimization problems through particle swarm optimization, "** *Int. J. Natural Comput.*, 2002, 1, (2–3), pp. 235–306.

[15] Yasuda, K., Ide, A., and Iwasaki, N.: **"Adaptive particle swarm optimisation, "** *Proc. IEEE Int. Conf. Systems, Man and Cybernetics,*October 2003, Vol. 2, pp. 1554–1559.

[16] Ting, T.O., Rao, M.V.C., and Loo, C.K.: **"A novel approach for unit commitment via an effective hybrid particle swarm optimisation, "** *IEEE Trans. Power Syst.,* 2006, 21, (1), pp. 411–418.

[17] Shi, Y., and Eherhan, R.C.: **"A modified particle swarm optimizer, "** *Proc. IEEE Congress on Evolutionary Computation (CEC),* 1998,pp. 69–73.

[18] Yoshida, H., Kawata, K., Fukuyama, Y., Takayama, S., and Nakanishi, Y.: **"A particle swarm optimization for reactive power and voltage control considering voltage security assessment, "** *IEEE Trans. Power Syst.,* 2000, 15, (4), pp. 1232–1239.