Gravitational Search Algorithm for Bidding Strategy in Uniform Price Spot Market

Ajay Bhardwaj [1], Dr. Tanuj Manglani[2]

[1]*M. Tech. Scholar, YIT, Jaipur*
[2]*Professor, YIT, Jaipur*

***Abstract** - In a deregulated market environment, Generation Companies (GENCOs) develop bidding strategies to increase their benefits. Electricity Markets (EMs) are not perfectly competitive due to limited number of power producers, large investment size and various transmission constraints. In this oligopolistic market environment, it is of great interest for generation companies to develop bidding strategies to share maximum profit. In this work, an optimal bidding strategy has been developed for a GENCO whose profit is to be maximized by using Gravitational Search Algorithm (GSA). The approach has been applied on four generator test system and compared with the results obtained from Genetic Algorithm (GA) and Particle Swarm Optimization (PSO).*

***Key Words*: Electricity Markets, Gravitational Search Algorithm, Genetic Algorithm, Particle Swarm Optimization, System Operator**

1. INTRODUCTION

Restructuring of the power system means eradicating the monopoly in the generation and transmission trading sectors thereby introducing competition at various levels. Economic power market in which the participants separately submit their favored schedules, this market is called pool market. The system operator (SO) allot the dispatches of generators using an optimal power flow (OPF) which admits bid submitted by the participants as their input. Participants in competitive electricity pool market (EPM) develop strategic bidding in order to maximize their own profits. This problem is known as 'Power transaction game', which can be modeled as static non co-operative incomplete game with perfect information [1]. The game is static due to the fact that the process of decision making is applied for all the players involved. Non-cooperative means that each individual player is pursuing for his own interest and the incomplete information means players lack full information on the mathematical structure of the game. Perfect information stands for the fact that all players have full information of all strategies in primary stages.

Electricity generators (sellers) and electricity dealers/customers (buyers) have to introduce a transmission network for rolling the power from the generation point to the consumption point. Thus, unified transmission system is considered to be a natural monopoly so as to avoid the duplicity, huge investment for beginning and to take the advantage of the unified network viz. reduced installed capacity, increased system reliability and improved system performance.

For SO, it is necessary to explore strategic bidding behavior of participants in order to recognize probable power market abuse and limit it by presenting EPM rules and regulation. In past years, considerable amount of research papers has been presented on optimal bidding strategies for number of generators for exploring the market power in EPM.

There are number of simulation methods proposed by researchers to form bidding strategy such as dynamic programming [2], stochastic optimization [3]-[6], two level optimization [7]-[9], lagrangian relaxation [10]-[11], genetic algorithm [12]-[13], fuzzy approach [14], game theory [15]-[16]. Supply side bidding strategies are classified in pool markets [17]-[18] and bilateral markets [19]-[22].

Dynamic programming approach was presented in [2]. The approach was applied on England- Wales type electricity markets. In [2], Probability distribution function (PDF) was used to predict rival's behavior and supplier's bid was calculated by stochastic optimization technique. Song et al. [4] proposed Markov Decision Process (MDP) to estimate optimal bids of suppliers. Monte Carlo method is used in [5] to model supply function. In [6], Zhejiang provincial model was taken as pilot market and step wise bidding technique was applied for bidding problem. In [7], a two level optimization procedure was proposed to solve strategic bidding problem. The market operator decide the optimal bid to be selected while taking social welfare into account. A centralized economic dispatch is used to determine MCP and output of generators for a profitable bid in [8]. In [9], each suppliers bids a linear supply function based on probabilistic estimation of demand and rival's behavior. Langrangian relaxation based approach [10] is adopted to form bidding curve for England-Wales type electricity markets. The MCP is assumed to be known which is not practical case in real electricity markets. Zhang et al. [11] applied same approach in New England market in which rival's bids are assumed to be in discrete distributions. Gentic algorithm approach [12] is used to develop the bidding strategy in day ahead electricity market. Same methodology is adopted for spinning reserve

market in [13]. Widjaja et al. [14] presented fuzzy logic approach to handle uncertainty in electricity markets. Ferrero et al. [15] discussed competitive behavior of generator and eventual conditions that can form to exploit imperfect competence structure of market. Max-min criterion is used to make decisions based on bidding strategies. Co-operative game theory approach is presented in [16] which adopts a less rigid attitude in which each player can negotiate to develop the rules of the game before starting it. In [17], an optimal bidding strategy is developed for a generator to maximize its profit under step-wise bidding protocol.
In this work, gravitational search algorithm (GSA) [18] is proposed to form bidding strategy for a particular generator. The results are compared with GA and PSO algorithm.

2. PROBLEM DESCRIPTION

We assumed a system with N+1 generators in which each generator submit its bid in a sealed envelope to market operator in a day ahead market. An optimal bidding strategy has been developed to maximize the profit of generator X. Hence, there are N rivals of generator X in the market. Each generator has only one registered unit and they bid for one hour trading period.
Generator bids in multiple blocks for mitigating risk of losing the bid to rivals under the bidding protocol employing the uniform Market clearing price (MCP). Let us assume that N^{th} rival bids i blocks with block capacity $\widetilde{P}_i^n$ and block price $\widetilde{C}_i^n$ and if i=3, then the generator can bid for three blocks with their respective block capacity and block price.
We have neglected the effect of inter-temporal operating constraints of generators as bidding strategies are developed for one-period (one hour) auction only. Hence, for generator X, the objective of profit maximization can be formulated as:

Maximize $\phi(\alpha, p) = \alpha \times p \times t - R(p,t)$ (1)

Subject to:

$$0 \le p \le P \quad (2)$$

$$C_{\min} \le C \le C_{\max} \quad (3)$$

The objective given in (1) is subjected to constraints (2) and (3) to determine block price C. α is MCP, p is generator X's dispatched output and t is the time for the trading period which is 1 hr. in this paper. R(p, t) is the production cost function of generator X. C_{min} and C_{max} are upper and lower limits constraints on the bid price of the block.
The production cost function of generator is given as:

$$R(p,t) = (a + bp + cp^2) \times t \quad (4)$$

a, b and c are generator cost coefficients.
We can predict rival's behavior from historical data. Suppose that, rival's bidding prices $\widetilde{C}_i^n$ follow a normal probability distribution function (PDF).

$$PDF(\widetilde{C}_i^n) = \frac{1}{\sqrt{2\pi\sigma_i^n}} \exp\left(-\frac{(\widetilde{C}_i^n - \mu_i^n)^2}{2(\sigma_i^n)^2} \right) \quad (5)$$

μ_i is the mean value and σ_i is the standard deviation of prices of rival generators.
By predicting rival's behavior through probability distribution function, the process of finding the optimal bidding strategy for generator X with the objective function (1) with constraints (2) and (3) becomes a stochastic optimization problem which is to be solved by gravitational search algorithm which is presented in next section.

3. GRAVITATIONAL SEARCH ALGORITHM

In recent years, many metaheuristic algorithms are introduced which mimics natural processes and behavior of species namely Grey Wolf [19]-[20], Ant Lion [21] and natural physical laws like Gravitational Law. Rashedi et.al [18], anticipated a new meta-heuristic algorithm called GSA in year 2009. A beautiful analogy between Newton's gravitational laws with the optimization prototype of the era is presented in the algorithm. The postulates of the algorithm say that every particle attracts towards each other and force exerted between two objects (agents) is proportional to the mass of the objects and inversely proportional to square of the distance between them. Force causes a global movement of all objects towards the objects with heavier mass. Heavier mass is analogous to the agent which has higher fitness values. GSA propose four prepositions of a gravitational mass: its position, inertial mass, gravitational mass (active and passive).The position of mass is representation of a solution and masses are specified by fitness of a function. It is assumed that given a system with N agents in search space represents solution to a problem. Equation represents space dimension and the position of the agent in x_i^d d^{th} dimension.

$$X_i = \left(x_i^1, \ldots\ldots x_i^d, \ldots\ldots x_i^n \right), \quad for\ i = 1,2,\ldots\ldots,N \quad (6)$$

According to the Newton's law of attraction the force exerted by i^{th} mass due to j^{th} mass at time *t* represented by equation(5).

$$F_{ij}^{d}(t) = G(t)\frac{M_{pi}(t)\times M_{qj}(t)}{R_{ij}(t)+\varepsilon}\left(x_j^d(t) - x_i^d(t)\right) \quad (7)$$

Where $M_{pi}(t), M_{qj}(t)$ are active and passive gravitational mass, *G (t)* is gravitational constant at time *t* and R_{ij} is euclidian distance between *i* and *j* agents defined by equation (8).

$$R_{ij}(t) = \left\| X_i(t), X_j(t) \right\|_2 \quad (8)$$

Force exerted on an agent *i* is randomly weighted sum of the forces exerted from other agents.

$$F_i^d(t) = \sum_{j=1, j\neq i}^{m} rand_j \; F_{ij}^d(t) \quad (9)$$

Acceleration of the agent at time t in the d^{th} dimension on law of motion is used directly to calculate the force. In accordance with this law, acceleration is proportional to the force exerted and inversely proportional to mass of the agent.

$$a_i^d(t) = \frac{F_i^d(t)}{M_{ii}(t)} \quad (10)$$

Searching strategy of the algorithm is defined by updating velocity and position at time t and in d dimension.

$$v_i^d(t+1) = rand_i \times v_i^d(t) + a_i^d(t) \quad (11)$$

$$x_i^d(t+1) = x_i^d(t) + v_i^d(t+1) \quad (12)$$

The gravitational constant G, randomly at the starting and according time to control the search accuracy G is exponentially decayed.

$$G(t) = G(G_0, t) \quad (13)$$

$$G(t) = G_0\, e^{-\frac{\alpha t}{T}} \quad (14)$$

There α is a user specified constant, t is the current iteration and T is the total number of iterations.

$$M_{ai} = M_{pi} = M_{ii} = M_i \qquad i = 1,2\ldots\ldots,N \quad (15)$$

$$m_i(t) = \frac{fit_i(t) - worst(t)}{best(t) - worst(t)} \quad (16)$$

A heavy mass has a higher pull on power and moves slower so at the end of iteration the masses obtain will be having high on gravity and value of fitness is more.

Equation (18), (19) and (20), where *fit(t)* represent fitness value of the agent at time t and best and worst masses in population. In order to solve optimization problem each agent is specified with the position after each iterations the fitness is calculated and position and velocity of the agents are updated with each iteration ease of use.

$$M_i(t) = \frac{m_i(t)}{\sum_{j=1}^{N} m_j(t)} \quad (17)$$

For minimization problem

$$worst(t) = \max_{j\in\{1\ldots.m\}} fit_j(t) \quad (18)$$

$$best(t) = \min_{j\in\{1\ldots.m\}} fit_j(t) \quad (19)$$

For maximization problem

$$best(t) = \max_{j\in\{1\ldots.m\}} fit_j(t) \quad (20)$$

$$worst(t) = \min_{j\in\{1\ldots.m\}} fit_j(t) \quad (21)$$

4. SIMULATION RESULTS

This section presents the simulation results of optimal bidding problem for 4 generator power system. The optimization routine with the aim of maximizing the profit of generator 1 has been established. The optimal scheduling has been obtained from the optimization process with the aim of profit maximizing. The proposed method is implemented by using MATLAB 2013R and run on a Pentium IV CPU, 2.69 GHz, and 1.84 GB RAM computer. Three cases are being considered for analyzing the proposed method:

Case 1 : When mean and deviation of the energy price is same.

Table-1 : Parameters of Generator G and its Rivals

		Rival 1 (n=1)	Rival 2 (n=2)	Rival 3 (n=3)	
Block 1 (i=1)	Q_i^n	200	200	200	Block 1 (i=1)
	μ_i^n	10	10	10	
	σ_i^n	3	3	3	
Block 2 (i=2)	Q_i^n	200	200	200	Block 2 (i=2)
	μ_i^n	30	30	30	

	σ_i^n	3	3	3	
Block 3 (i=3)	Q_i^n	200	200	200	Block 3 (i=3)
	μ_i^n	50	50	50	
	σ_i^n	3	3	3	

Case 2: When mean of energy price is different and deviation is same

Table 2 : Parameters of Generator G and its Rivals

		Generator G	Rival 1 (n=1)	Rival 2 (n=2)	Rival 3 (n=3)
Block 1 (i=1)	Q_i^n	200	200	200	200
	μ_i^n	10	5	8	10
	σ_i^n	3	3	3	3
Block 2 (i=2)	Q_i^n	200	200	200	200
	μ_i^n	30	25	28	30
	σ_i^n	3	3	3	3
Block 3 (i=3)	Q_i^n	200	200	200	200
	μ_i^n	50	45	48	50
	σ_i^n	3	3	3	3

Case 3: When mean and deviation of the energy price are different.

Table 3 : Parameters of Generator G and its Rivals

		GENCO G	Rival 1 (n=1)	Rival 2 (n=2)	Rival 3 (n=3)
Block 1 (i=1)	Q_i^n	200	200	200	150
	μ_i^n	10	10	5	5
	σ_i^n	3	3	2	2
Block 2 (i=2)	Q_i^n	200	200	200	150
	μ_i^n	30	30	15	15
	σ_i^n	3	3	2	2
Block 3 (i=3)	Q_i^n	200	200	200	150
	μ_i^n	50	50	25	25
	σ_i^n	3	3	2	2

Table 4 : Simulation Results of Case 1 for 1500 MW Demand

Generators	Block	GA		PSO		GSA	
		Quantity Dispatched	Profit	Quantity Dispatched	Profit	Quantity Dispatched	Profit
Generator G	Block 1 (i=1)	102.3231	9843.609	100.7686	9998.332	50.84733	12783.62
	Block 2 (i=2)	131.9642		128.5571		180.1219	
	Block 3 (i=3)	144.6637		150.2417		195.2287	
Rival 1	Block 1 (i=1)	104.271	9657.957	102.9785	9741.634	76.74595	10219.85
	Block 2 (i=2)	129.6656		123.8611		83.83877	
	Block 3 (i=3)	141.1299		146.1022		178.1779	
Rival 2	Block 1 (i=1)	102.9752	9627.1	101.9354	9691.616	30.25509	12467.5
	Block 2 (i=2)	130.4406		122.9692		166.3012	
	Block 3 (i=3)	139.9518		145.2727		193.0143	
Rival 3	Block 1 (i=1)	103.2864	9605.031	102.4722	9857.289	50.19605	10699.07
	Block 2 (i=2)	129.4298		125.4121		126.6048	
	Block 3 (i=3)	139.8991		148.2496		168.6678	

Table 5 : Simulation Results of Case 2 for 1500 MW Demand

Generators	Block	GA		PSO		GSA	
		Quantity Dispatched	Profit	Quantity Dispatched	Profit	Quantity Dispatched	Profit
Generator G	Block 1 (i=1)	109.3476	9858.975	85.59075	10972.45	72.7872	12602.35
	Block 2 (i=2)	132.2891		134.1445		169.7263	
	Block 3 (i=3)	145.753		173.3165		196.5737	
Rival 1	Block 1 (i=1)	92.06842	7678.541	78.27468	8273.012	38.89709	8936.899
	Block 2 (i=2)	127.5911		119.0776		80.18483	
	Block 3 (i=3)	138.2678		157.4763		186.6779	
Rival 2	Block 1 (i=1)	103.6156	8823.837	83.13933	9622.634	44.80174	11544.46

	Block 2 (i=2)	128.9227		125.3144		165.0685	
	Block 3 (i=3)	140.0813		162.3632		191.1482	
Rival 3	Block 1 (i=1)	109.8087	9665.054	87.43988	10539.26	18.66821	11857.24
	Block 2 (i=2)	130.6444		128.7376		149.2373	
	Block 3 (i=3)	141.6106		165.1252		186.2296	

Table 6: Simulation Results of Case 3 for 1500 MW Demand

Generators	Block	GA		PSO		GSA	
		Quantity Dispatched	Profit	Quantity Dispatched	Profit	Quantity Dispatched	Profit
Generator G	Block 1 (i=1)	115.8906	10326.85	94.0055	11889.25	71.74701	11639.62
	Block 2 (i=2)	134.6478		156.1378		158.379	
	Block 3 (i=3)	155.6669		186.5392		177.0104	
Rival 1	Block 1 (i=1)	114.3701	10009.24	93.96751	11621.1	119.5045	11537.35
	Block 2 (i=2)	133.0438		149.9842		140.8614	
	Block 3 (i=3)	149.2956		182.5315		184.722	
Rival 2	Block 1 (i=1)	99.53949	3462.764	88.72192	3644.606	54.82075	4664.045
	Block 2 (i=2)	123.7431		115.3485		149.6374	
	Block 3 (i=3)	129.9855		142.7393		185.3774	
Rival 3	Block 1 (i=1)	103.9339	3279.676	83.08818	3055.067	26.55673	3542.609
	Block 2 (i=2)	117.8889		96.49795		111.0197	
	Block 3 (i=3)	120.9947		110.4385		120.3635	

Discussion

Table 1, 2 and 3 shows three cases being considered to test the efficacy of the presented methodology. From table 4, it is evident that GSA performs better in comparison to GA and PSO when mean and deviation of energy price of generators are taken different. Profit achieved by PSO and GA is less than by 21.78 % and 22.99 % respectively in comparison to GSA. Table 5 shows the results for case 2. Also, In this case, bidding strategy formed by using GSA is giving better results. The profit obtained is less than by 12.93 % and 21.76 % by using GA and PSO respectively in comparison to GSA. In case 3, as shown in Table 6, PSO performs better and slightly more profit is obtained in comparison to GSA. GA again got trapped in local minima and gives 13.14 % less profit in comparison to PSO. When comparing with GSA, it gives 11.27 % less profit.

5. CONCLUSION

In this work, an optimal bidding strategy is developed for a particular generator whose profit is to be maximized. The results show that GSA performs better for

most of the cases considered in comparison to GA and PSO algorithm.

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AUTHOR PROFILE

Ajay Bhardwaj received B.Tech. degree in Electrical Engineering from Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur, India. Presently, he is pursuing M.Tech. degree from Yagyavalkya Institute of Technology, Jaipur, India. His research interest includes power system restructuring, electricity economics, power trading and power system optimization.

Dr. Tanuj Manglani received his M.Tech and Ph.D in Electrical Engineering in 2010 and 2014 respectively. His research interest includes optimization techniques, artificial intelligence (AI) applications to power system operation and control, electricity markets, and distributed generation. Presently he is Professor of Electrical Engineering at YIT, Jaipur, India.