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AN EFFECTIVE METHODOLOGY FOR PROFIT AND BENEFIT MAXIMIZATION OF MARKET PARTICIPANTS BY TRADING OF ELECTRIC ENERGY UNDER COMPETITIVE ENVIRONMENT

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ABSTRACT

The electricity market has since 1980's been gradually evolving from a monopoly market into a liberalized one for encouraging competition and improving efficiency. This introduces the opportunity for market participants (Power suppliers and consumers) to make more profit and benefits in the trading process of electrical energy. Therefore, it has become a core interest for the market participants to develop optimal bidding strategies to maximize the profit and benefits while participating in a competitive energy market. In this paper an optimal bidding strategy for market participants associated with risk management is devised as a multi objective stochastic optimization problem and solved by Firefly algorithm. (FA). The Firefly Algorithm is a Meta heuristic, nature inspired, optimization algorithm which is based on the social flashing behavior of fireflies and has been introduced for the bidding problem to obtain the global optimal solution. The impact of risk on the GENCOs is analyzed by introducing the factor λ. The proposed FA approach effectively maximizes the GENCOs profit and benefit of large consumers. A numerical example with six suppliers and two large consumers is considered to illustrate the essential features of the proposed method and test results are tabulated. The simulation result shows that these approaches effectively maximize the Profit and Benefit of Power suppliers and Large Consumers, converge much faster and more reliable when compared with existing methods.

INTRODUCTION

Recent changes in the electricity industry in several countries have led to a less regulated and more competitive energy market. The process of changing of intensely regulated monopoly industry to a deregulated electricity market paves the way for better allocation of power resources. The Deregulated market supplies reliable power to the end customers at lower cost. It consists of day-ahead energy market, real-time energy market and ancillary services market (Mohammad Shahidehpour *et al.,* 2000; Mohammad Shahidehpour *et al.,* 2002). Day-ahead electricity markets are emerging as an important medium through which power is allocated in many deregulated environments. Therefore, in a deregulated environment, Generation companies (GENCOs) are facing with the problem of optimally allocating their generation capacities to different markets for profit maximization purposes. Moreover, the GENCOs have greater risks than before because of the significant price volatility in the spot energy market introduced by deregulated system.

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Bidding strategies become essential for maximizing profit and have been extensively studied (Dhanalakshmi *et al.,* 2011; Wen and David 2001; David and Fushuan 2001; David and Wen 2001; Vasileios *et al.,* 2004). Usually, optimal bidding strategies are based on the GENCOs own costs, anticipation of other participants, bidding behaviors and power system operational constraints. The PoolCo model is a widely employed electricity market model (Dhanalakshmi *et al.,* 2011). In this model GENCO develop optimal bidding strategies, which consist of sets of price–production pairs. The ISO implements the market clearing procedure and sets the market clearing price (MCP) (Wen and David 2001). Theoretically, GENCOs should bid at their marginal cost to achieve more profit. However, the electricity market is more akin to an oligopoly market and GENCOs may achieve benefits by bidding at a price higher than their marginal cost. Therefore, developing an optimal bidding strategy is essential for achieving the maximum profit and has become a major concern for GENCOs. Identifying the potential for the abuse of market power is another main objective in investigating bidding strategies (Mohammad Shahidehpour *et al.,* 2002).

In general, strategic bidding is an optimization problem and has been discussed by many researchers in their literatures. It can be found that the researcher have solved the bidding problem by conventional (Wen and David 2001; David and Fushuan 2001; David and Wen 2001; Vasileios *et al.,* 2004; Rajkumar *et al.,* 2004; Eng Zhao *et al.,* 2010; Guan *et al.,* 2001; De la Torre *et al.,* 2002; Bakirtzis *et al.,* 2007; Conejo *et al.,* 2002; Daoyuan Zhang *et al.,* 2000; Somgiat Dekrajanjpetch and Gerald Sheble 1999) and non-conventional (heuristic) techniques (Yamin, and Mohammad Shahidehpour 2004; Azadeh *et al.,* 2012; Rocio Herranz *et al.,* 2012; Pathom Attaviriyanupap *et al.,* 2005; Yucekaya *et al.,* 2009; Vijaya Kumar and Vinoth Kumar 2011; Bajpai and Singh 2007; Soleymani *et al.,* 2011). Dynamic programming (Wen and David 2001), Monte carlo (David and Fushuan 2001; David and Wen 2001; Vasileios *et al.,* 2004), game theory (Rajkumar *et al.,* 2004; Eng Zhao *et al.,* 2010), Mixed integer linear programming (Guan *et al.,* 2001; De la Torre *et al.,* 2002; Bakirtzis *et al.,* 2007; Conejo *et al.,* 2002) and lagrangian relaxation (Daoyuan Zhang *et al.,* 2000; Somgiat Dekrajanjpetch and Gerald Sheble 1999 Yamin, and Mohammad Shahidehpour 2004) are the examples of conventional methods. Bidding problem was addressed for the first time by A.K David (Wen and David 2001). In this work, a conceptual optimal bidding model was developed and solved by Dynamic programming technique for England-Wales electricity markets. Here each supplier is required to bid for a constant price for each block of generation. System demand variations and unit commitment costs were also considered in the model. Wen and David (David and Fushuan 2001; David and Wen 2001; Vasileios *et al.,* 2004) have described the strategic bidding as a stochastic optimization problem and it is solved by using Monte Carlo method for single period auction. An importance is given to competitive generators and large consumers while maximizing their own benefits. Game Theory and non game theory based bidding strategies are another approach and are briefly explained in references (Rajkumar *et al.,* 2004; Eng Zhao *et al.,* 2010). In (Rajkumar *et al.,* 2004; Eng Zhao *et al.,* 2010), the competition among participants is modeled as a non-cooperative game with incomplete information. The imperfect information of the suppliers is analyzed by game theory and Nash equilibrium has been identified . In (De la Torre *et al.,* 2002; Bakirtzis *et al.,* 2007; Conejo *et al.,* 2002), a mathematical method based on Mixed Integer Linear Programming (MILP) is suggested. Here an appropriate forecasting tool is used to estimate the probability density function of next day hourly market clearing price. This probabilistic information is used to formulate the self scheduling profit maximization problem. Lagrangian relaxation (LR) method is applied in (Daoyuan Zhang *et al.,* 2000; Somgiat Dekrajanjpetch and Gerald Sheble 1999) for solving optimization-based bidding and self-scheduling where a utility bids part of its energy and self-schedules the rest as in New England. The model considers ISO bid selections and uncertain bidding information of other market participants. In some cases it is difficult to formulate a mathematical model using objective function and constraints. Under these circumstances conventional methods may not be suitable for solving bidding problem.

Heuristic methods are different methodology, which provides best solution through its global searching behavior. It includes Genetic Algorithm (GA), Simulated Annealing (SA), Evolutionary Programming (EP), Particle Swarm Optimization (PSO) and Hybrid approaches among them. In reference (Yamin, and Mohammad Shahidehpour 2004; Azadeh *et al.,* 2012), an optimal bidding strategy for the power suppliers are framed as a optimization problem and it is solved by GA. A method to analyze the optimal bidding strategy of generation companies including the emission constraint is discussed in (Rocio Herranz *et al.,* 2012). In this method simulated annealing (SA) technique is adopted to find the best solution and it is compared with other intelligent optimization algorithms. Pathom Attaviriyanupap *et al.* (2005) formulated a bidding strategy for a day-ahead electricity market. In this paper optimal bidding parameters were determined by solving an optimization problem which includes the general constraints of Unit Commitment (UC). The problem becomes non-linear and non-differentiable which was difficult to solve by traditional optimization algorithm. So the author proposed a technique based on Evolutionary Programming to solve the problem. PSO is a natural search algorithm (Yucekaya *et al.,* 2009), (Vijaya Kumar and Vinoth Kumar 2011) and is used to find an optimal solution for strategic bidding problems. But it takes much computational time to offer the best solution. To overcome this problem, a hybrid method such as Fuzzy-PSO (Bajpai and Singh 2007) and SA-PSO (Soleymani *et al.,* 2011) has been suggested to obtain the global best and optimal solution.

In this paper, the problem of developing bidding strategies for the market participants (Power suppliers and Consumers) associated with risk management is modeled as an optimization problem in the oligopolistic electricity market. The Meta heuristic approach of Firefly algorithm (FA) is applied to solve the bidding strategy problem. The proposed approach gives global optimal solutions and effectively maximizes profit of power suppliers (GENCOs) and benefit of large consumers.

PROBLEM FORMULATION

Mathematical Model

In the competitive Electricity market, Independent Power Producers (IPPs) and large consumers are participating in bidding methodologies for their own benefits. The mathematical model of Pool based Electricity Market are presented in Fig 1.

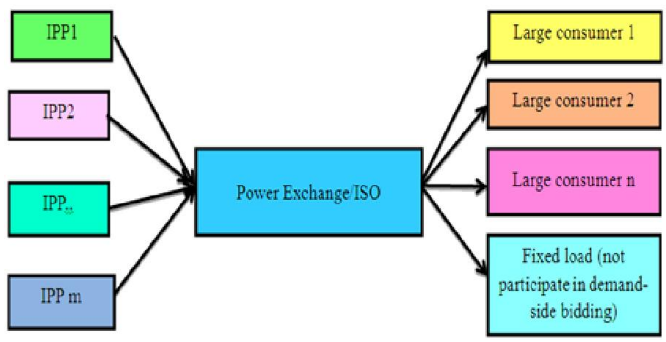

Fig 1. Mathematical of Model Electricity Market

Let m Independent Power Producers bid Linear supply curve denoted by $R = a_i + b_i P_i$ where i=1, 2… m and n large consumers bid linear demand curve denoted by $R = c_j - d_j L_j$ where j=1, 2… n. Independent system operator (ISO) will receive bid from all market participants. Using predicted aggregate load from small users, ISO will determine MCP that will balance the energy demand and Supply. This process is graphically expressed in fig 2.

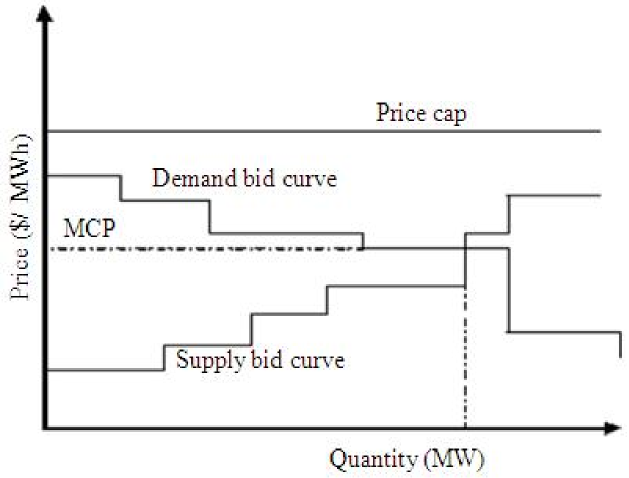

Fig 2. Market clearing price

The objective of independent power producers is to maximize their profit. Suppose the i^{th} power producer has cost function, which is denoted by

$$C_i(P_i) = e_i P_i + f_i P_i^2 \quad (1)$$

The objective function of independent power producer can be defined as:

$$Max : F(a_i, b_i) = \sum_{i=1}^{m} RP_i - \sum_{i=1}^{m} C_i(P_i) \quad (2)$$

Similarly, the objective of large consumer is to maximize their benefit. Suppose the j^{th} large consumer *has* revenue function denoted by

$$B_j(L_j) = g_j L_j - h_j L_j^{\,2} \quad (3)$$

The objective function of large consumer can be defined as:

$$Max : G(c_j, d_j) = \sum_{j=1}^{n} B_j(L_j) - \sum_{j=1}^{m} R_j L_j \quad (4)$$

Market Clearing Price (R) is represented by the following equation

$$R = \frac{Q_0 + \sum_{i=1}^{m} \frac{a_i}{b_i} + \sum_{j=1}^{n} \frac{c_j}{d_j}}{K + \sum_{i=1}^{m} \frac{1}{b_i} + \sum_{j=1}^{n} \frac{1}{d_j}} \quad (5)$$

The aggregated load demand is formulated as

$$Q(R) = Q_o - KR \quad (6)$$

Where

Q_o = Constant number.

K = Coefficient of the price elasticity of the aggregate Demand.

Constraints

1. Power balance constraints:

$$\sum_{i=1}^{m} P_i = Q(R) + \sum_{j=1}^{n} L_i \quad (7)$$

$$p_i = \frac{R - a_i}{b_i} \qquad i = 1,2....m \quad (8)$$

$$L_j = \frac{c_j - R}{d_j} \qquad j = 1,2....n \quad (9)$$

2. Power generation limit constraints:

$$p_{i\min} \le p_i \le p_{i\max} \qquad i = 1,2......m \quad (10)$$

3. Power consumption limit constraints:

$$L_{j\min} \le L_j \le L_{j\max} \qquad j = 1,2......n \quad (11)$$

Risk analysis

The function of power suppliers is to deliver power to a large number of consumers. However the demands of different consumers vary in accordance with their utilities. The changes in demand shows that load on a power companies never constant, rather it varies from time to time. Most of the complexities of modern power companies operation arise from the inherent variability of the load demanded by the users. Because of these load fluctuations and nature of participants, each GENCO is subjected to market risk. So, while making bidding strategies these risk factors also be considered to maximize the profit of market participants. It is experienced from the probability theory; the role of variance of the profit is used to estimate thes risk of the day ahead investment. Based on this methodology, the proposed optimal bidding strategy for the i^{th} GENCO with its operational risk may be formulated as

Maximize

$$F(a, b) = (1 - \lambda)E(F) - \lambda D(F) \quad (12)$$

Subject to

$$P_{i\min} \le \frac{(E(R) - a_i)}{b_i} \le P_{i\max} \quad (13)$$

Where

$E(F)$ - Expected value of the profit

$D(F)$ - Standard deviation of the profit

$E(R)$ - Expected value of market clearing price

λ - Risk factor

λ is referred as a risk factor and is used as a scale to measure the impact of risk on the GENCO and it can be varied from 0 to 1.There is no risk for a company when λ is equal to zero. As a result, the company yields maximum profit. Rather, if λ is equal to one then the company is subjected to condition of risk. So in this condition, the prime objective is to minimize the risk. Normally, the power producers should study and balance these two conflicting parameters such as profit maximization and risk minimization. The methodology developed to balance these two parameters depends upon the value of λ. In this paper, an elegant approach for improving the profit of market participants by including the various degree of risk factor is suggested. Hence there are two bidding coefficients (a_i, b_i). By keeping a_i as constant and b_i is varied till the system reaches its maximum profit. The best coefficient b_i is identified by solving the problem with the help of Firefly algorithm.

PROPOSED METHODOLOGY

Overview of Firefly algorithm

The firefly algorithm (FA) is a meta heuristic, nature inspired, optimization algorithm which is based on the social flashing behavior of fireflies, or lighting bugs, in the summer sky in the tropical temperature regions (-3, 20). It was developed by Dr. Xin-she yang at Cambridge university in 2007, and it is based on the swarm behavior such as fish, insects, or bird schooling in nature (Xin-She Yang *et al.,* 2012; Chandrasekaran and Sishaj P. Simon 2012).

Function of firefly algorithm

Attractiveness

The attractive function of firefly is a monotonically decreasing function: Where, r is the distance between any two fireflies, β_0 is the initial attractiveness at r =0, and γ is an absorption coefficient which controls the decrease of the light intensity.

$$\beta(r) = \beta_0 \exp(\gamma r^m) \quad With\ m \geq 1 \tag{14}$$

Distance

The distance between any two fireflies i and j, at positions x_i and x_j respectively, can be defined as a Cartesian Euclidean distance as follows:

$$R_{ij} = |x_i - x_j| = \sqrt{\sum_{k=1}^{d} (x_{i,k} - x_{j,k})^2} \tag{15}$$

Where $x_{i,k}$ is the component of the spatial coordinate x_i of the k^{th} firefly and d is the number of dimensions. In 2D case we have

$$R_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \tag{16}$$

However, the calculation of distance R can also be defined using other distance metrics, based on the nature of the problem, such as Manhattan distance or mahalanobis distance.

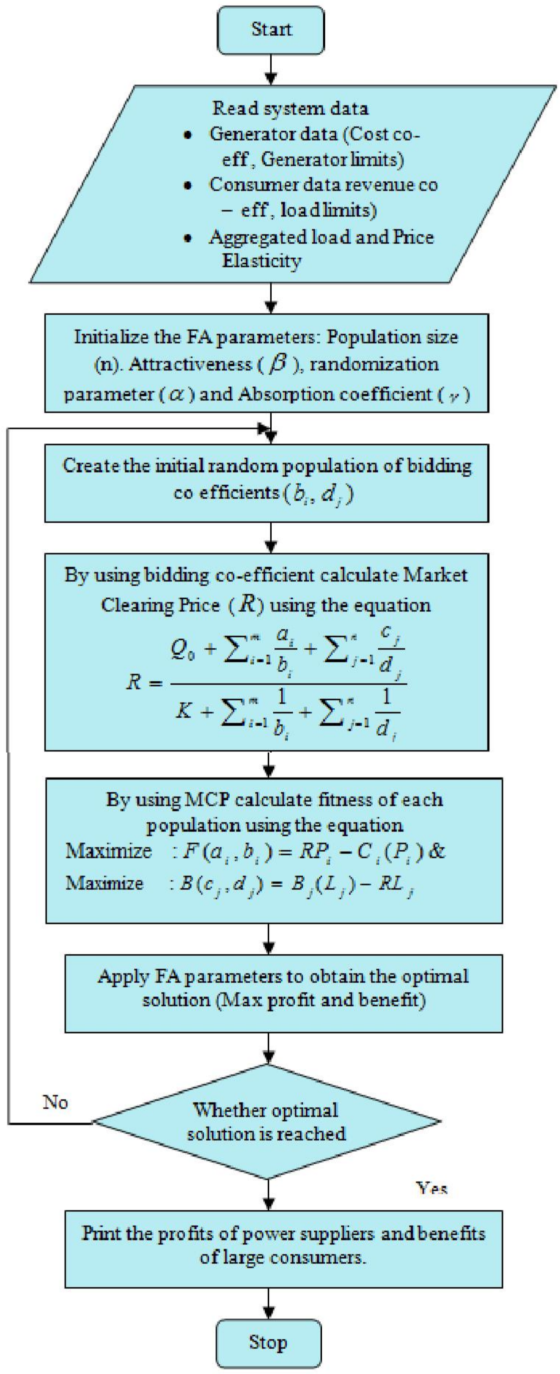

Fig.3. Flow chart of proposed method

Movement

The movement of the Firefly i which is attracted by a more attractive (i.e. brighter) firefly j is given by the following equation:

$$x_i^{t+1} = x_i^t + \beta_0 \exp(-\gamma r^2_{ij})(x_j - x_i) + a\left(rand - \frac{1}{2}\right) \quad (17)$$

Where the first term is the current position of a Firefly, the second term is used for considering a firefly's attractiveness to light intensity seen by adjacent fireflies, and the third term is used for random movement of a firefly when the brighter ones are not available. The coefficient a is a randomization parameter determined by the problem of interest, while rand is a random number generator uniformly distributed in the space which is (0,1)..

Implementation of Firefly Algorithm

Firefly Algorithm has four essential parameters, Population size (n), Attractiveness (β), randomization parameter (α) and Absorption coefficient (γ).The feasible parameters obtained by iterative processes are as follows. α = 0.2–0.9, β = 0.2–1.0, γ= 0.1–10 and n = 25–50. Therefore, the following parameters of the proposed FA are considered to solve the optimal bidding problem of six independent power producers and two large consumers. Where n= 30, $\beta = 0.20$, $\alpha = 0.25$, $\gamma = 1$ and maximum number of iterations = 5000. The flow chart for proposed method shown in Fig 3.

Owing to the random nature of the FA, their performance cannot be judged by the result of a single run. Many trials with independent population initializations should be made to obtain a useful conclusion of the performance of the approach..To demonstrate the superiority of the proposed FA, the test results are also compared with the results already reported by the most recently published methods such as PSO, GA and Monte Carlo method for solving the bidding problem. All scenarios are programmed in MATLAB 9.0 and simulation is carried on a computer with a Pentium IV, Intel Dual core 2.2 GHz, 2 GB RAM.

CASE STUDY AND RESULTS

The proposed Firefly approach has been applied to a test system given in reference (David and Fushuan 2001) which consists of six Independent power Producers (GENCOs) and two large consumers.

The cost coefficients of power generation and maximum/ minimum limits of six Independent power Producers given in Table-1. Similarly revenue cost coefficients and load consumption limits of two large consumers are listed in Table-2. The fuel cost function of each generator and revenue cost function of consumers is estimated into quadratic equation. The parameters associated with the load characteristics are considered from the same reference (Wen and David 2001) where in aggragated load Q_0 is equals to 300MW and price elasticity K equals to 5. The simulation results of Independent power Producers and large consumers are presented in Table–3 and Table-4. It is evident from fig. 4 the total profits and benefits of the proposed method have been improved than the other available methods. This is due fact that the FA algorithm plays a vital role in search of the global optimal solution. Also, comparison of market clearing price and total profits of market participants are presented in Table – 5.

Table 1. Data of power suppliers

GENCOs	e (\$/h)	f (\$/MWh)	P_{imin} (MW)	P_{imax} (MW)
1	6.0	0.01125	40	160
2	0.25	0.0525	30	130
3	3.0	0.1375	20	90
4	9.75	0.02532	20	120
5	9.0	0.075	20	100
6	9.0	0.075	20	100

Table 2. Data of large consumers

Large Consumers	g (\$/h)	h (\$/MWh)	L_{jmin} (MW)	L_{jmax} (MW)
1	30	0.04	0	200
2	25	0.03	0	150

Sometimes, there may be a chance to the suppliers to receive erroneous market information. At that time, the variation of profit of the supplier is analyzed by changing the value of risk factor (λ), using the equation (12) subjected to constraint (13). The simulation results of the second supplier for various value of λ and corresponding change in profit against risk factor are shown in Table -6.

Table 3. Simulation results for power suppliers

GENCOs	Bidding Strategy($/MW)	MCP ($/hr)	Bidding Power(MW)	**Revenue ($)**	Fuel Cost ($)	Profit ($)
1	0.0656	16.482	160.00	**2637.120**	1248.00	1389.120
2	0.1214		92.50	**1524.585**	934.828	589.756
3	0.2647		51.00	**840.502**	510.637	329.945
4	0.0834		84.00	**1384.488**	987.668	396.820
5	0.1716		41.25	**679.880**	496.867	183.013
6	0.1716		41.25	**679.880**	496.867	183.013
					Total Profit	3071.667

Table 4. Simulation results for large consumers

Large Consumers	Bidding Strategy ($/MW)	MCP ($/hr)	Bidding Load (MW)	Revenue ($)	Marginal Cost ($)	Benefit ($)
1	0.0876	16.482	169.00	3927.56	2775.458	1152.102
2	0.0706		141.95	2944.416	2339.78	604.636
					Total Benefit	1756.738

Table 5. Comparison of MCP and total profits of market participants

	FA(Proposed)	PSO	GA	Monte Carlo
MCP ($/hr)	16.482	16.47	15.81	16.35
Total Profits($)	4828.405	4741.3	4554.2	4723.9

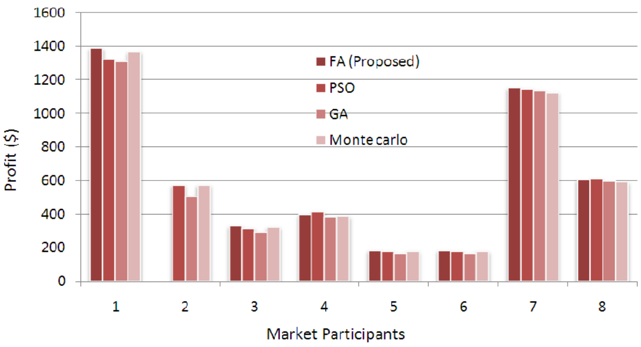

Fig. 4 Comparison of profit of market participants

Table 6. Profit of GENCO by considering risk

Risk Factor (λ)	E(F)	D(F)	Profit($)
0	589.76	40.35	589.76
0.3	588.02	40.01	397.99
0.5	582.14	39.20	268.77
0.7	489.06	33.63	119.40
0.9	477.29	27.02	18.56
0.9335	469.67s	23.37	4.95

From the results, it is clear that the proposed method provides maximum profits and benefits compared to existing methods. Also, it converges much faster and more reliable than the other available methods. the computational time of the proposed method is much reduced.

Conclusion

In this paper, Firefly Algorithm (FA) is applied to solve bidding strategy problem in order to improve the profit and benefit of Independent power Producers and two large consumers with risk management in an open Electricity market. In this approach, each participant tries to maximize their profit with the help of information obtained from the system operator. The simulation result has been compared with Particle Swarm Optimization (PSO), Genetic Algorithm (GA) and Monte Carlo method. The algorithm can be easily used to develop the bidding strategy in different market rules, different fixed load, different capacity of buyers and sellers. The results obtained from the proposed method confirm the feasibility and reliability of FA algorithm as an efficient methodology in analyzing the optimal bidding strategy of market participants.

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Appendix: A

Nomenclature

$F(a_i, b_i)$	Profit of i^{th} electricity producer
$G(c_j, d_j)$	Benefit of j^{th} large consumer
$C_i(P_i)$	Cost function of i^{th} electricity producer
$B_j(L_j)$	Revenue function of j^{th} large consumer
P_i	Output power of i^{th} electricity producer
L_j	Load power of j^{th} large consumer
$Q(R)$	Aggregated load demand
Q_o	Constant number of aggregated load demand
K	Price elasticity of the aggregate Demand
P_{imax}	Maximum output limits of unit *i*.
P_{imin}	Minimum output limits of unit *i*.
$L_{j\max}$	Maximum Power consumption limit of j^{th} Consumer
$L_{j\min}$	Minimum Power consumption limit of j^{th} Consumer
M	Number of generating units
n	Number of consumers
a_i, b_i	Bidding co-efficient of the i^{th} generator
c_j, d_j	Bidding co-efficient of the j^{th} consumer
GENCO	Generation Company
FA	Firefly algorithm

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