Developing an Optimization Method for Bidding Strategies in an Open Electricity Market

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***Abstract*—Deregulation of power sector has highly maximized competition of market by reforming conventionally integrated utility of power into competitive EM. Purpose of this research is to develop an optimization method by combining the genetic algorithm, adaptive metropolis search, particle swarm optimization and differential evolution methods for strategy of optimal bidding in an open electricity market. Maximum profit for power exchange and optimal result has been obtained with minimum convergence with the proposed algorithm. Developed algorithm gives much faster convergence of the optimal result Further the proposed algorithm can be expanded for complicated power system issue of optimization under deregulated environment.**

***Index Terms*—particle swarm optimization, genetic algorithm, adaptive metropolis search, Electricity Market (EM), optimization method**

I. Introduction

Restructuring the power sector mostly focus at eliminating the monopoly in trading and generation sectors and thus pioneering competition at probable levels. Sudden modifications in EM (electricity markets) have a numerous new problems like market's oligopolistic nature, strategic bidding of supplier, misuse of power in the market, demand of price elasticity and more [1]-[3]. Thus, in a competitive EM, supplier has to bid at their cost of marginal production to increase payoff. Anyhow, practically EM are oligopolistic in nature and suppliers of power might seek to maximize their gain by bidding an amount higher than cost of marginal production. Understanding their constraints of technical aspects and their expectation of market and rival behavior, own costs, suppliers facing the issue of building the best and appropriate optimal bid. This is referred as issue of strategic bidding [4], [5].

Further, it was pointed out by [6], [7] that process of modifying of regulated monopoly sector to a deregulated EM paves the ways for appropriate allocation of resources of power [8], [9]. Deregulated EM provides reliable power to final users at minimal cost. It involves day-ahead, real-time energy market as well as market for ancillary services [10]. Strategies for bidding had become significant for maximizing profit [10]-[13]. Generally OBS (optimal bidding strategies) were based on generation firms own costs, bidding behaviors, anticipations of other customers and operational constraints for power system [12], [13].

A. *Problem Identified*

Each corner of the globe pursues to be opened for EM among competitive forces. Pioneering competition to EM would make them effective. EM through the globe was influenced by vertically combined utilities which undergo huge process of restructuring [10]. In EM, generating firms and large customers require models for bidding for maximizing their profits. However, each large customer and supplier would bid strategically for selecting coefficients for countering the competitor's strategy for bidding [14]-[16]. For that, heuristic approaches like GA (Genetic algorithm), PSO (Particle swarm optimization), simulated annealing and integrating these approaches were adopted for obtaining an optimal solution for strategic issues of bidding [17], [18]. Therefore, this study intends to focus on developing the algorithm by combining the genetic algorithm, particle swarm optimization, adaptive metropolis search and differential evolution methods for strategy of optimal bidding in an open electricity market.

B. *Aim and Objectives*

Aim of the research is to develop the algorithm by combining the genetic algorithm, AMS, PSO and evolutionary algorithms for OBS in an open electricity market

- To identify the problems in strategy of optimal bidding with specific reference to open electricity market
- To develop the combined algorithm and evolution methods for OBS in an open electricity market

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- To obtain faster convergence of power exchange of optimal result

This paper is organized as follows. Section II discusses about prior studies to strategy of optimal bidding with specific reference to open electricity market. Section III presents the detail on the development of the combined algorithm and evolution methods for OBS in an open electricity market. In Section IV, the simulation results on the bidding strategy will be presented and it shows faster convergence than previous methods.

II. Literature Review

Kumar and Kumar [19] examined problems in OBS (optimal bidding strategy) using GA. GA applications were mainly utilized for approach of bidding strategy (BS) is developed for large customers and suppliers in an OEM (open electricity market). In such kind of approach, each user attempt to increase their profit through information gained by operator in the system. Unsymmetrical and symmetrical information of competitors were discussed and noticed that, participant who have not accurate information does not get enough profit. Similarly algorithm developed in this study also provides same result as simulation of Monte Carlo with high profit, fast convergence and much less effort in computation. This algorithm could be easily adopted for determining the OBS in unique rule of market, capacity of sellers and buyers and fixed load. Further, Kumar *et al.* [20] developed a methodology on the basis on fuzzy adaptive PSO to prepare OBS by generation firms (GF) for gaining high profits in a day-ahead EM (electricity market). PSO was one of effective tool to solve complicated issues in optimization. PSO outcomes are greatly relied on weight of inertia and method mostly has issues of being identified in domestic optima. For overcoming these pitfalls of PSO, weight of inertia was adjusted in fuzzy adaptive PSO using rules of fuzzy IF/THEN. It was observed that fuzzy adaptive PSO gives rapid convergence and more profit and thus it is applicable for applications of real-time.

Dwivedi *et al.* [21] presented PSO algorithms for determining quantities and bid prices under rules related to competitive market of power with using constraint emission. Purpose of research is the potential effects of emissions trading on electricity markets and power industries. Maximizing environmental regulations and issues have forced GENCOs (Generation companies) for reviewing the policies were adopted for long-term planning. In this research PSO provides the international optimum solution. PSO perform effectively for obtaining price of bidding of single generator and its potential for controlling the convergence. For obtaining an optimal solution, parameters of PSO were determined. It was demonstrated that with emission, profit would be less, when taken into consideration, when carbon cost is responsible for, the circumstance would become worse as well as price is higher than costs coverage would need but the focus over an imperfect market in electricity paired with trading of emissions is justified.

Asokan and Kumar [22] developed quantum inspired PSO (QPSO) for solving BS to enhance the profit and gain large customers and power suppliers linked with management of risk in OEM. Results from simulation were compared with method of Monte Carlo and GA. Outcomes acquired from QPSO method show the high profits and gain over other methods. It was indicated that approach of QPSO is a prominent technique to solve difficult optimization issue in power system under environment which is deregulated. Kumar *et al.* [23] proposed a PSO application for OBS for power suppliers as well as more number of customers without and with coefficient of risk in OEM. Competitive prices for bidding are denoted as variables of stochastic with function of probability density. Approach of PSO has certain benefits than other algorithms. Effectiveness of PSO was tested on 30-bus system and compared with GA for every one hour demand without and with risk constraint. It was noticed that robustness and feasibility of approach related to PSO is an effective tool to determine OBS of GS in OEM.

Jonnalagadda and Mallesham [24] developed an algorithm of Shuffled Frog Leaping (SFL) for solving the BS for GF in a competitive EM. It is metaheuristic in memetic that is on the basis of memes evolution conducted by interactive individuals as well as information exchange for global among population of frog. It integrates benefits of social behavior-oriented algorithm of PSO and genetic-based MA (memetic algorithm) with these characteristics like little adjustment in parameter, easy deployment and simple concept, formation of prompt, great and high potential in global search. It was observed that SFLA performed well in terms of convergence of Central Processing Unit (CPU) time and total profit than GA and PSO algorithms. According to study by Asokan and Kumar [25] have adopted FA (firefly algorithm) for solving the issue in BS for enhancing profit and gain of individual producers of power and 2 large customers with management of risk in OEM. It was clear from the outcomes that reliability and feasibility in the algorithm of FA was an effective methodology to analyze OBS of market inhabitants.

III. Research Design

An algorithm by combining the genetic algorithm, AMS, PSO and differential evolution methods for OBS in an open electricity market was studied. In this study, operational method used in the study is the combination of the GA, PSO and adaptive metropolis search and differential evolution methods.

GA:

GA (Genetic algorithm) is employed for searching suitable solutions for issues in combinatorial optimization. GA starts with solutions set namely population. Each and every solution is denoted by set of chromosome or bit string. A new population will be formed by taking solutions from single population. Based on their fitness, solutions are selected for forming new offspring or solutions. Higher the values of fitness then there is higher opportunities to reproduce. Fig. 1 explains the flowchart of Genetic Algorithm (GA) OB process using GA can be explained as followed.

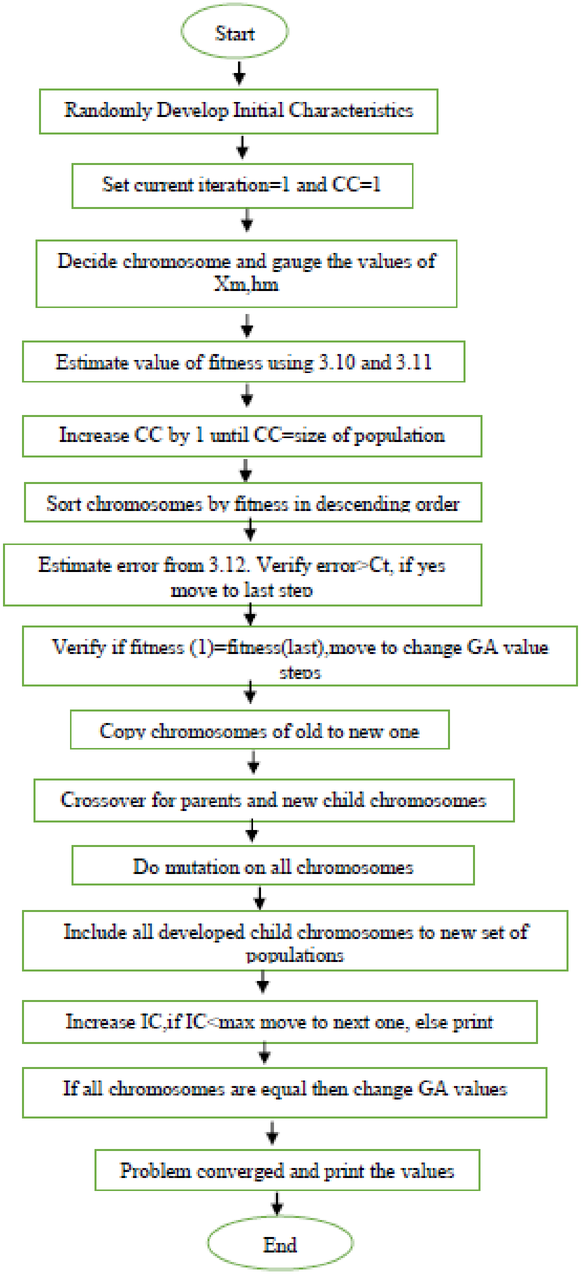

Figure 1. Flowchart of GA algorithm.

Necessary data for the GA will be read in the first step, such as generators' cost coefficients (CC) c_i, a_i (m=1,2,....n) and customers CC b_i, d_i (k=1,2,...r), tolerance of convergence, step size, error and max allowed iterations, size of population, string length S, crossover probability c_p, mutations probability m_p, lambda max, min. In the 2nd step, randomly initial chromosomes population has to be generated. Iteration count (IC) was initiated as "(1)", in the 3rd step. Chromosome count was initiated as 1 in the 4th step. In the 5th step, chromosome has to be decoded and actual values will be calculated using actual value of j_m, h_k. In the 6th step, fitness values will be calculated using equation "(6)", and "(7)",

$$r_m + s_m T_m = U \quad m=1,2..n \tag{1}$$

$$x_k + w_k Vm = U \quad k=1,2..r \tag{2}$$

$$\sum_{m=1}^{n} Tm = O(U) + \sum_{k=1}^{r} Vm \tag{3}$$

$$T_{\min} \le T_m \le T_{\max} \quad m=1,2,..n \tag{4}$$

$$V_{\min} \le V_k \le V_{\max} \quad k=1,2,..r \tag{5}$$

Maximize:

$$G(r_m s_m) = UT_m - x_m T_m \tag{6}$$

Subject to equations (1) - (5)

Maximize:

$$S(x_k w_k) = S_k(V_k) - UV_k \tag{7}$$

Subject to equations (1) - (5)

In the 7th step, increase the count in the chromosome by "(1)", and repeat the process from 4th step until count in the chromosome is equal to size of population. In the 8th step, chromosomes and all their associated data will be sorted in the fitness' descending order. In the 9th step, estimate error from equation "(8)", verify if the error is > than tolerance of convergence. If yes, move to 17th step.

$$F_m(r_k, s_k) = \frac{1}{2\pi\sigma_k^r \sigma^s_{\sqrt{1-\mu k^2}}} * \exp\{-\frac{1}{2\sqrt{1-\mu k^2}} \left[\begin{array}{c} \left(\frac{r_k - \gamma_k^{(r)}}{\sigma_k^{(r)}}\right) x^2 - \\ \frac{2\mu k^2 \left(r_k - \gamma_k^{(r)}\right)\left(s_k - \gamma_k^{(s)}\right)}{\sigma_k^{(r)} - \sigma_k^{(s)}} + \\ \left(\frac{s_k - \gamma_k^{(s)}}{\sigma_k^{(s)}}\right) x^2 \end{array} \right] \} \tag{8}$$

where $x = \frac{r_k - \gamma_k^{(r)}}{\sigma_k^{(r)}}$ and $\left(\frac{s_k - \gamma_k^{(s)}}{\sigma_k^{(s)}}\right)$ respectively

In the 10th step, verify if fitness "(1)", is equal to fitness (last), If yes move to 16th step. In the 11th step, copy E_p chromosomes of old population to new one beginning from best populations from top. Crossover will be performed in the 12th step on selecting parents and new child chromosomes (CCS) will be generated, repeat the procedure to obtain needed quantity of chromosomes. In 13th step, mutation is performed on all chromosomes. All the generated CCS to new population has to be added in the 14th step. Increase IC in the step 15. If IC<max. Iteration, proceed to next iteration, or else print issue not converged in maximum iterations number. In the 16th step, all chromosomes in the population had equivalent value if the simulation convergences. By changing the parameters in GA, program has to be run once again. In the 17th step, issue converged. Further, print the values of j_m, h_k at which customers and suppliers get maximum advantage.

AM (Adaptive Metropolis) algorithm adopts evaluated covariance of distributing the target in the proposal distribution [26]. Evolutionary algorithms (EA) were developed as an approach for revolutionary to solve optimization and solve issue that involves various conflicting objectives. At the same time, it was noted that other than their potential for searching that is hard to deal with high spaces for various solutions, such algorithms for maintaining a various solutions population and utilizing solutions' commonalities by recombination. Main enhancements in evolutionary search efficiency could be obtained by running various algorithms for optimization for adopting new concepts of international sharing of information and adaptive creation of offspring. This approach is referred as multialgorithm, AMALGAM or genetically adaptive multiobjective for evoking the procedure image that combines the strengths of various algorithms for optimization [27].

To integrate the other optimization algorithms into the GA, instead of implementing a single operator for reproduction, we simultaneously use the other individual algorithms, such as PSO, GA and ASM algorithm and evolutionary methods, to generate the offspring. These algorithms each create a prespecified number of offspring points from the parents using different adaptive procedures. After creation of the offspring, a combined population is created and will be ranked using fast non dominated sorting (FNS). By comparing the current offspring with the previous generation, elitism is ensured because all previous non dominated members will always be included in the next generation. Finally, members for the next population are chosen from subsequent non dominated fronts of the parent based on their rank and crowding distance. The new population is then used to create offspring using the method described below, and the aforementioned algorithmic steps are repeated until convergence is achieved. Fig. 1 depicts the detailed flowchart of the proposed method.

A. Limitations of the Research

- This study focuses only on the open electricity market alone.
- This research combines the PSO, GA and ASM algorithm and evolutionary algorithms for OBS in an open electricity market.
- This research exclusively considers about developing the algorithm by combining the genetic algorithm, AMS, PSO and evolutionary algorithms for OBS in an open electricity mark.

IV. Results and Discussion

Optimization method selected for this research combines GA, AMS and PSO and evolution algorithms to obtain much faster and best convergence of optimal result. Table I illustrates the advantages the proposed methods over conventional algorithms used so far in this approach.

Fig. 2 explains the market clearing price and the profit of the power exchange. x axis represent the market clearing price (MCP) and y axis denotes the profit of the power exchange. As the algorithm of optimizations needs to search a minimum goal function, thus a minus symbol is added to give a correct goal function.

TABLE I. Performance of Various Algorithms

S. No	Author	Year	Result
1	Kumar and Kumar	2011	It was found out that MCP of PSO was 16.47, MCP of GA was 15.81, MCP of Monte Carlo was 16.35. Proposed algorithm performs well in terms of MCP value.
2	Kumar and Kumar	2011	The performance of GA is similar to Monte Carlo simulation with less effort for computing, more profit and fast convergence.
3	Kumar et al	2012	Fuzzy adaptive PSO algorithm produces rapid convergence and more profit than other algorithms
4	Jonnalagadda et al	2013	MCP value of shuffled frog leaping algorithm was 9.45, MCP value of PSO was 6.88, MCP value of GA was 6.69 and MCP value of Monte Carlo was 6.08. It was clear that proposed algorithm MCP value was high.

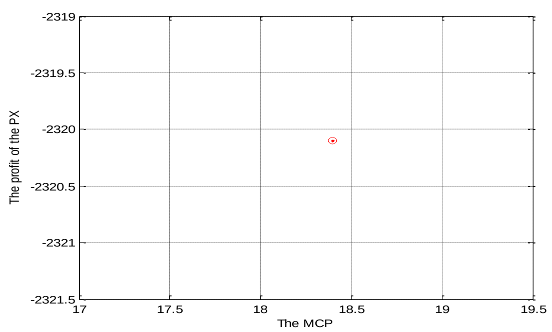

Figure 2. Market clearing price vs profit of the power exchange.

When observing the performance of various algorithms, proposed method could able to convergence at minimum iterations than other algorithms like GA, PSO and more.

V. Conclusion

In this study, the work is mainly focused on the developing the algorithm by combining the genetic algorithm, AMS, PSO and evolutionary algorithms for OBS in an open electricity market. Here, optimization method combines the GA, PSO, AMS and evolution methods, thus it could able to give much faster convergence of the optimal result. It was observed from Table I that developed method could able to convergence at minimum iterations than other algorithms like PSO, GA and so on. It was found out that maximum profit for power exchange and optimal result was obtained with minimum convergence with the proposed algorithm. For future work, the developed algorithm work can be expanded for complicated power system issue of optimization under deregulated environment.

REFERENCES

[1] A. K. David and F. S. Wen, "Strategic bidding in competitive EM: A literature survey," in *Proc. IEEE PES Summer Meeting*, 2000, pp. 2168-2173.

[2] A. K. David and F. S. Wen, "Optimally co-ordinate bidding strategies in energy and ancillary service markets," in *Proc. IEEE Gener. Trans. Distrib.*, 2002, pp. 331-338.

[3] D. Zhang, *et al.*, "Optimization based bidding strategies in deregulated market," in *Proc. IEEE PES Power Industry Computer Applications Conf.*, 1999, pp. 63-68.

[4] H. Ebrahim, *et al.*, "Fast consumption of pure strategy nash equilibrium in EM cleared by merit order," in *Proc. IEEE Trans, Power System*, 2010, pp. 722-728.

[5] J. Wang, *et al.*, "An evolutionary game approach to analysing bidding strategies in EM with elastic demand," *Energy*, vol. 36, no. 5, pp. 3459-3467, 2011.

[6] M. Shahidehpour, H. Yamin, and Z. Y. Li, *Market Operations in Electric Power Systems: Forecasting, Scheduling and Risk Management*, New York: Wiley, 2002.

[7] M. Shahidehpour and M. Alomoush, *Restructured Electrical Power Systems, Operation, Trading, and Volatility*, New York: Wiley, 2000.

[8] A. J. Conejo, F. J. Nogales, and J. M. Arroyo, "Price taker bidding strategy under price uncertainty," *IEEE Transactions on Power Systems*, vol. 17, no. 4, pp. 1081-1088, 2002.

[9] X. Guan, Y. Ho, and F. Lai, "An ordinal optimization based bidding strategy for electric power suppliers in the daily energy market," *IEEE Transactions on Power Systems*, vol. 16, no. 4, pp. 788-793, 2001.

[10] F. S. Wen and A. K. David, "Strategic bidding for electricity supply in a day-ahead energy market," *Electrical Power System Research*, vol. 59, pp. 197-206, 2001.

[11] S. Dhanalakshmi, S. Kannan, and K. Mahadevan, "Market models for deregulated environment –A review," in *Proc. IEEE ICETECT*, 2011, pp. 82-57.

[12] A. K. David and F. S. Wen, "Optimal bidding strategies for competitive generators and large consumers," *Electrical Power and Energy Systems*, vol. 23, no. 1, pp. 37-43, 2001.

[13] V. P. Gountis and A. G. Bakirtzis, "Bidding strategies for electricity producers in a competitive electricity market place," *IEEE Transactions on Power Systems*, vol. 19, no. 1, pp. 356-365, 2004.

[14] D. N. Simopoulos, S. D. Kavatza, and C. D. Vournas, "Unit commitment by an enhanced simulated annealing algorithm," *IEEE Transaction on Power Systems*, vol. 21, no. 1, pp. 68-76, 2006.

[15] B. Venkatesh, T. Jamtsho, and H. B. Gooi, "Unit commitment – A fuzzy mixed integer linear programming solution," *IET Generation, Transmission & Distribution*, vol. 1, no. 5, pp. 836-846, 2007.

[16] M. V. Pereira, *et al.*, "Strategic bidding under uncertainty: A binary expansion approach," *IEEE Trans, Power System*, vol. 1, pp. 180-188, 2005.

[17] S. Torre, *et al.*, "Price maker self-scheduling in a pool-based EM: A mixed-integer LP approaches," *IEEE Trans. Power System*, vol. 4, pp. 1037-1042, 2002.

[18] S. Torre, *et al.*, "Finding multi-period Nash equilibrium in ool-based EM: A mixed-integer LP approaches," *IEEE Trans. Power System*, vol. 4, pp. 643-651, 2004.

[19] J. Kumar and D. M. Kumar, "Optimal bidding strategy in an open electricity market using genetic algorithm," *International Journal of Advance, Soft Computational Applications*, vol. 3, no. 1, pp. 1-14, 2011.

[20] J. Kumar, *et al.*, "Bidding strategies for generation companies in a day-ahead market using fuzzy adaptive particle swarm optimization," *WSEAS Transactions on Power Systems*, vol. 7, issue 3, pp. 136-144, 2012.

[21] K. Dwivedi, *et al.*, "Competitive bidding in electricity markets with carbon emission by using PSO," in *Proc. International Multiconference of Engineers and Computer Scientists*, Hong Kong, 2012.

[22] K. Asokan and R. Kumar, "Modeling of bidding strategies for power suppliers and large consumers in electricity market with risk analysis," *International Journal of Soft Computing and Engineering*, vol. 3, no. 2, pp. 271-276, 2013.

[23] J. Kumar, *et al.*, "Bidding strategy considering risk by generating companies in an open electricity market using particle swarm optimization," *International Journal of Energy Engineering*, vol. 3, no. 1, pp. 7-11, 2013.

[24] V. Jonnalagadda and V. Mallesham, "Bidding strategy of generation companies in a competitive electricity market using shuffled frog leaping algorithm," *Turkish Journal of Electrical Engineering and Computer Sciences*, vol. 21, pp. 1567-1583, 2013.

[25] K. Asokan and A. Kumar, "An effective methodology for profit and benefit maximization of market participants by trading of electricity energy under competitive environment," *International Journal of Development Research*, vol. 4, no. 3, pp. 525-531, 2014.

[26] H. Haario, E. Saksman, and J. Tamminen, "An adaptive metropolis algorithm," *Bernoulli*, vol. 7, no. 2, pp. 223-242, 2001.

[27] J. A. Vrugt and B. A. Robinson, "Improved evolutionary optimization from genetically adaptive multimethod search," in *Proc. National Academy of Sciences of the USA*, vol. 104, no. 3, pp. 708-711, 2007.

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