IOSR Journal of Engineering (IOSRJEN) www.iosrjen.org
ISSN (e): 2250-3021, ISSN (p): 2278-8719
Vol. 08, Issue 01 (January. 2018), ||V2|| PP 74-80

Strategic Bidding Issues in Power System: An Empirical State-of-the-Art Developments

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Abstract—Strategic bidding issues in electricity markets are extensively investigated in power systems, often by modeling multifaceted bi-level optimization issues, which are hard enough to resolve. The conventional approach for resolving such issues is to redesign them as MILPs. Anyhow, the computational time of such MILP modelings rises considerably, once there is an increase in the size of network. In addition, scheduling horizon also rises, and randomness is taken into account. This survey intends to review various topics to solve strategic bidding issues. Accordingly, the algorithmic classification for the surveyed papers was analyzed and portrayed. In addition, the performance measures and the maximum performance achievements are also analyzed and demonstrated in this survey.

Keywords— Strategic bidding; MILP; GENCO; Bid price; classification.

Nomenclature

Acronyms	Description
MILPs	Mixed-Integer Linear Programs
MPC	Marginal Production Cost
LR	Lagrangian Relaxation
SVM	Support Vector Machines
ANN	Artificial Neural Network
GenCos	Generation Companies
DisCos	Distribution Companies
RDC	Residual Demand Curve
SFLA	Shuffled Frog Leaping Algorithm
G-MA	Genetic-based Memetic Algorithm
PSO	Particle Swarm Optimization
GA	Genetic Algorithm
FAGSA	Fuzzy Adaptive Gravitational Search Algorithm
SA	Simulated Annealing
SFE	Supply Function Equilibrium
NSA	Numerical Sensitivity Analysis
SPSO–TVAC	Self-organising hierarchical PSO with Time-Varying Acceleration Coefficients
DE	Differential Evolution
GSA	Gravitational Search Algorithm
HSA	Harmony Search Algorithm

I. INTRODUCTION

Reorganization of the power industry chiefly intends in eliminating the issues in the production and selling sectors, thus, establishing antagonism at diverse stages whenever it is feasible [1] [2]. However, the unexpected alterations in the power environment have several new problems like seller's strategic bidding [24] [25], the oligopolistic environment of the market, market power mishandling, and cost flexibility, etc. [3] [4]. Hypothetically, in a entirely economical approach, trader have to bid at their MPC [5] [6] [7] to increase the payoff, but, sensibly the power fields were oligopolistic in nature, and power distributors may seek to enhance their revenue by bidding a price superior than MPC. With the knowledge of their own expenditure, technical parameters and their anticipation of rival and market activities, distributors meet with the issue of setting up the excellent bid. This is referred as a strategic bidding issue [8] [9] [10].

Strategic bidding [11] [12] was investigated from two major viewpoints. The major widespread design evaluates the probable impact of market supremacy on the aforesaid market result, which causes the capability

of market representatives to act tactically. The second viewpoint is to introduce the issue from the standpoint of a GenCo in search to optimize its energy transaction on the spot market depending on its structure of cost, collection and functioning parameters[13] [14].

During the last decade, several studies were carried out to find out the best bidding policy depending on various market designs, where game theory and optimization equilibrium approaches are the well known. In optimization, the issue is resolved for a specific individual by disregarding the bidding behaviors of other players' [15] [16]. Throughout this process, a GENCO or customer initially predicts the rivals' bidding strategies and MCP and then resolves a profit maximization issue by means of a suitable method, namely, dynamic, stochastic dynamic programming or fuzzy linear [17] [18]. However, approximating the rivals' bidding strategies and MCP is extremely complex and, after performing it, the real gains may considerably differ from forecasts as it is regarded that the LMP is not based on the submitted players' bids [19] [20].

This survey has reviewed various works related to the strategic bidding issues. Here, various algorithmic classifications, which are adopted in the surveyed papers, are demonstrated along with their performance measures. Along with it, the maximum performances achieved by the various works are also portrayed by this survey. The paper is organized as follows. Section II analyzes the various related works and reviews done under this topic. In addition, section III explains the analysis on bidding strategies, Section IV provides the research gaps and challenges and Section V concludes the paper.

II. LITERATURE REVIEW

*A. **Related works***

In 2017, Forhad *et al.* [1] have adopted a technique that was designed as a bi-level optimization issue, where, at lower level, the social welfare of community was increased by resolving a power flow issue, whereas, at upper level, the gains of bidders were increased. For resolving the high predicaments, two approaches were implemented and, moreover, an interior point approach was deployed. Accordingly, standard issues in four diverse scenarios were resolved and their outcomes were distinguished with those attained from two traditional schemes and the literature that points out that the suggested model has certain advantage concerning efficiency and quality.

In 2017, Steeger and Steffen [2] has exploited a dynamic convexification scheme, which utilizes Lagrangian Relaxation (LR) and it moreover facilitates the designing of non-convex multi-stage issues by means of decomposition schemes. To overcome the problems related with designing the MILP, the bidding decision was modeled, which exploits both Benders decomposition and LR. Finally, the effectiveness of adopted algorithm was revealed by a descriptive model, which shows its superiority.

In 2017, Clements *et al.* [3] have established a technique, which was very much associated to the happening of increased price occurrences. Moreover, rebidding performance instantaneously after extreme price events were exposed to have reverse impacts on the market function. The important information was that endorsement of electricity markets competition can comprise disagreeable consequences if the market policy was not cautiously designed to contradict strategic performance by market contestants.

In 2016, Pinto *et al.* [4] have established a SVM dependent model to offer decision support to the players of electricity market. This policy was analyzed and confirmed by being incorporated in ALBidS, and further, it was distinguished with the ANN that offers encouraging outcomes. From the simulation outcomes, an effectual electricity market price was estimated within a fast execution time when compared with other traditional schemes.

In 2015, Shivaie and Mohammad [5] have presented a novel technique for enhancing optimal bidding policy in secure power markets by regarding the effects of pollution, as further intentions. In the presented technique, both GenCos and DisCos attempt to increase their profit by executing various optimal approaches. Finally, the simulation outcome demonstrates the profitableness of the recently introduced model in attaining best possible bidding policies.

In 2014, Samuel et al. [6] have introduced a model, which initially examines how the outcomes of day-ahead sales have been influenced on rising access of renewable energy. The introduced scheme further details the utilization of RDC in this varying situation and above mentioned evaluation technique to calculate these curves. In addition, the description was illustrated with experimental outcomes and confirmations.

In 2014, Lim and Hak [7] have implemented an optimal bidding approach, which was attained by means of a Q-learning algorithm. The power consumers require bidding strategies in order to increase their profits. Hence, the adopted scheme was modeled in such a way, that it improves the gain of the power consumers. Moreover, a microgrid operation system was established to estimate the performance of the implemented bidding strategy, and an investigational analysis was also carried out.

In 2014, Vijaya Kumar and D. M. Vinod Kumar [8] have adopted a novel SFLA to resolve the bidding strategy issues. It merges the advantages of the G-MA and PSO. Owing to this, it includes improved accurate search that evades premature assortment of operators and convergence. Consequently, the adopted techniques

prevail over the drawbacks of using GA and PSO scheme. Finally, the outcome demonstrates that SFLA utilizes reduced computational time and it generates more profits when distinguished with conventional schemes.

In 2013, Vijaya Kumar and D. M. Vinod Kumar [9] have suggested a new stochastic optimization model to resolve bidding strategy issue by means of FAGSA. GenCos contribute in the bidding development with the intention of increasing their profits in the electricity market. The outcomes demonstrate that the adopted scheme could develop the solution quality, search behavior and it also offers reduced computational time when distinguished against benchmark stable parameter approaches.

In 2011, Soleymani [10] had proposed a novel technique related to bidding strategy, which exploits the amalgamation of SA and PSO in an electricity market. According to the suggested technique, Gencos organize their strategic bids based on SFE design, and they vary their strategies of bidding till Nash equilibrium points were attained. In addition, the performance of this method was distinguished against the outcomes of other conventional approaches namely, PSO, GA and an arithmetical technique (GAMS/DICOPT) and the superior outcomes of the adopted scheme was observed.

In 2011, Mahvi, Ardehali [11] has presented a novel technique for optimal bidding strategy determination between GenCos in the electricity markets by means of NSA and agent-based approach. Here, for authenticating the suggested technique, the outcomes attained from this analysis were distinguished with those obtainable in the literature. Finally, the comparison of outcomes illustrates an enhanced simulation time by and total reward percent when compared with other schemes.

In 2011, Boonchuay and Weerakorn [12] have established an excellent bidding strategy, which was attained using SPSO–TVAC. In addition, the established bidding strategy was executed and distinguished with other PSO constraints. Here, the test results point out that the implemented SPSO–TVAC model could offer an advanced MSR when compared with other PSO techniques. Finally, it was found that the suggested scheme was applicable to offer better risk minimization in GenCo spot market.

In 2009, Ahmet [13] had implemented two PSO approaches to find out the bid costs and quantities that abide by the norms of an economic market. The initial technique exploits a traditional PSO method to discover the solutions. In addition, the subsequent process has also exploited a decomposition approach in amalgamation with PSO design that considerably performs better than the traditional form of PSO. From the analysis, the nonlinear cost functions of PSO were found to offer advanced profits when compared with MPC-based bidding.

In 2009, Vahidinasab and S. Jadid [14] have adopted a bilevel optimization technique for introducing optimal bidding strategy that concerns emission of contaminants from suppliers. The adopted methodology deploys SFE approach to symbolize the strategic performance of every supplier. Here, the optimal power flow was exploited to resolve the emission of contaminants from suppliers, which were subjected to the supplier physical parameters and transmission limits. In addition, for demonstrating the adopted model under diverse conditions, various case studies were exploited, and the efficiency of the adopted scheme was proved.

In 2008, Gao *et al.* [15] have introduced two models for generating the market bidding performances on the basis of SVM. The initial approach was dependent on the price determining precision, with which the denial risk could be portrayed. Accordingly, the other approach considers the effect of own bid of producer and the risks related with the bidding was governed by the constraint setups. Finally, the implemented schemes have been analyzed with a mathematical illustration, and the results were obtained.

III. VARIOUS ANALYSIS ON BIDDING STRATEGIES

A. Algorithmic Classification

Various algorithms are adopted in the reviewed work, which comprises of techniques such as, GA, DE, MILP, SVM, HSA, RDC, Q-Learning scheme, SFLA, GSA, PSO, Agent-based approach and Fuzzy based method. Here, GA and DE have been adopted in [1], and MILP has been implemented in [2]. Accordingly, SVM has been suggested in [4] and [15], while HSA have been adopted in [5]. In addition, RDC has been presented in [6], and Q-Learning scheme has been adopted in [7]. SFLA and GSA have been implemented in [8] and [9] respectively. Moreover, PSO has been offered by [10] [12] and [13], while agent-based model has been adopted in [11]. Also, Fuzzy based approach was proposed in [14].

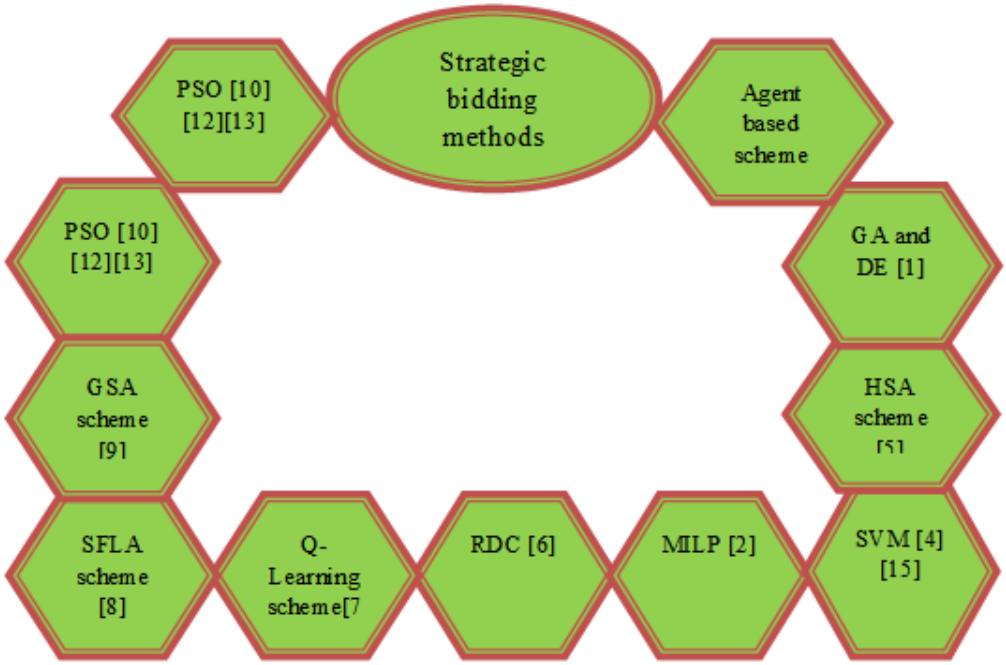

Fig. 1: Algorithmic classification of the reviewed works

B. ***Performance Measures***

The performance measures of the reviewed works are given by Table I. Various measures such as, price, maximum power, computational time, profit, line capacity, average power production, error values that are adopted by the surveyed works have been depicted in this section. Accordingly, price factor contributes about 46.67% of the total contribution, while maximum power contributes about 13.33% of the entire contribution. Also, computational time and profit metrics have presented about 20% and 33.33% of the entire contribution. In addition, line capacity, average power production, and error has offered about 13.33%, 20% and 26.67% of the total contribution. The other performance measures offered about 33.33% of the total contribution.

TABLE I. PERFORMANCE MEASURES ON VARIOUS REVIEWED WORKS

Citation	Price	Max power	Computational time	Profit	Line capacity	Average power production	Error	Others
[1]			✓	✓		✓		
[2]	✓		✓					
[3]	✓							✓
[4]			✓	✓				
[5]		✓		✓		✓		
[6]	✓							✓
[7]	✓							
[8]	✓	✓						
[9]				✓			✓	
[10]				✓				✓
[11]					✓			
[12]					✓			
[13]								✓
[14]	✓					✓		
[15]	✓							✓

*C. **Maximum Performance Achieved***

The maximum performance achieved by various performance metrics is given by Table II. The maximum price attained from the reviewed papers was found to be $1250, and the maximum power attained by the surveyed works was determined to be 600MW. Accordingly, the reduced computational time achieved by the reviewed papers is 0.02sec and the maximum profit attained from the surveyed papers was determined to be 2617.73MW. Also, the maximum line capacity and average power production were established to be 600MW and 80MW respectively. Performance metrics such as error and dispatched quantity has acquired about 0.001 and 500MW correspondingly. Moreover, reference RDC and dispatched Gencos have attained maximum performance values of 50MWh and 1300MW respectively. The mean, standard deviation, and market simulation have attained maximum values of 6616.9, 59.10 and 0.67M€ correspondingly.

TABLE II. MAXIMUM PERFORMANCE ACHIEVED BY THE REVIEWED WORKS

Measures	Maximum value	Citation
Price	$1250	[2] [3] [6] [7] [8]
Max power	600MW	[5][8]
Computational time	0.02Sec	[1][2][4]
Profit	2617.73MW	[1][4][5][9][10]
Line capacity	600MW	[11] [12]
Average power production	80MW	[1][5][14]
Error	0.001	[9]
Dispatched quantity	500MW	[3]
Reference RDC	50MWh	[6]
Dispatched Gencos	1300MW	[10]
Mean	6616.9	[13]
Standard deviation	59.10	[13]
Market simulation	0.67M€	[15]

*D. **Chronological Review***

The numerous papers concerned in this review are taken from various years ranging from 2008 to 2017. The papers taken from 2017 have offered 13% of the entire contribution and the surveys taken from the year, 2016 have offered 13% of the total contribution. In addition, the papers taken from 2015 and 2014 have presented 7% and 20% of the entire contribution. Accordingly, the surveys taken from the year 2013 and 2011 have offered about 7% and 20% of the entire contribution. Moreover, the papers taken the year 2009 and 2008 have presented about 13% and 7% of the entire contribution. The chronological reviews of the surveyed papers are demonstrated by Fig. 2.

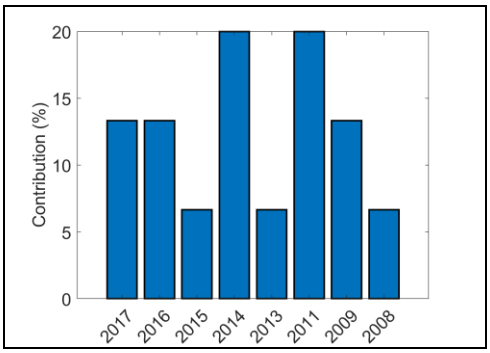

Fig. 2: Chronological review of the reviewed works

IV. RESEARCH GAPS AND CHALLENGES

Strategic bidding was considered as a major factor in real power markets. The key issues and challenges of strategic bidding are depicted in this section. For strategic bidding in competitive power markets, the contestants might cheat the system by untruthfully exposing their benefits/ costs on their bids/offers or schedules, and they would do it by incessantly varying one or more constraints of MPC. In addition, the potential for market power may be higher than various goods owing to very much reduced demand elasticity, increased cost of storage, rigorous elasticity parameters on generation and demanding investment on production plants. Accordingly, demand-side bidding improve the capability of customers to respond to increased price and make the market to function more effectively and satisfactorily. However, very least works have been made on

strategic bidding issues till date. Moreover, increased social welfare could be attained by allowing demand-side bidding and establishing suitable market regulations to strategic performance of distributors. An appropriate bidding architecture for several parameters such as, energy and ancillary services were still not obtainable, which remains as another major challenge. In addition, FACTS devices were renowned for enhancing the dynamic and static performances of the system. Such devices could also play a major role in dealing with the market power exploitation. Here, the vital constraint was to choose the excellent solution from both economic and technical viewpoint. The demand side management and power quality were still a challenging issue in power markets.

V. CONCLUSION

Strategic bidding issues in power markets are extensively scrutinized in power systems, often by modeling complex bi-level optimization issues, which were usually hard to resolve. In addition, the sudden variations that take place in the electricity markets include a variety of new problems such as oligopolistic nature of the market, market power misuse, supplier's strategic bidding, price-demand elasticity and so on. This paper has presented a survey on strategic bidding issues in power markets. Accordingly, in this survey, various papers were analyzed, and the corresponding techniques adopted in each surveyed paper were described. In addition, the performance measures concerned in each paper were illustrated and along with it, the maximum performance measures attained were also illustrated. Thus the survey provides the detailed analysis of the strategic bidding issues from the reviewed papers.

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IOSR Journal of Engineering (IOSRJEN) is UGC approved Journal with Sl. No. 3240, Journal no. 48995.

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