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A review on Demand-side tools in electricity market

R. Sharifi[a], S.H. Fathi[a,*], V. Vahidinasab[b]

[a] Electrical Engineering Department, Amirkabir University of Technology, Tehran, Iran
[b] Electrical Engineering Department, Shahid Beheshti University, Tehran, Iran

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ABSTRACT

With the advent of restructuring in the electricity markets, the Supply-side quickly adapted to the new environment, whereas, the story in the demand side has been different. Demand side dealt with the electric energy as a commodity available to the necessary extent. This caused the Supply-side to realize that the demand side would admit to purchase electric energy at any price, and this resulted in the advent of bidding strategies in the Supply-Side, known as "hockey-stick bidding". The most important result was transfer of the demand side assets to the Supply-side. After a while, the demand side noticed the self-sloppy condition, therefore looked for tools to deal with these threats. This subject is examined in this paper.

1. Introduction

Until a few decades ago, the government was responsible for management and control of the electric power system and it was rarely owned by the private sector. This exclusive structure of the power system was inefficient and did not ensure the benefits of producers. Solution for this problem was privatization and restructuring of the power system, which provided a competitive market at the levels of generation, transmission and distribution. In general, the electricity power industry, after privatization, was split into two parts:

- The Wholesale Sector
- The Retail Sector

The wholesale sector is comprised of the generation companies, which generate electric energy in high volume and transmit it to the load centers throw high-voltage transmission lines. In the next step, the retailer companies, on behalf of the Demand-side and, occasionally Big Consumers, purchase their required energy independently [1–8].

In Deregulated Electricity Market, until recently, only the generation companies in the wholesale sector would seek to compete with each other to sell their electric energy to customers with the objective of increasing their profit, yet the Demand-side had no function in this respect. In the other words, the Demand-side dealt with electric energy as a commodity is available to the required extent, which indicates its inflexibility. Overall, the Demand-side had not been adapted to the new environment. This incompatibility of the Demand-side caused the increasing greed ingeneration companies and soon it was realized that the Demand-side would yield to any price to purchase electric energy, resulting in the advent of bidding strategies in the Supply-Side, known as "hockey-stick bidding" [9].

Thus, the prodigious asset transfer, from the Demand-side towards the Supply-Side, may be viewed as the most important impact of restructuring until recently [10]. The primary reasons for this incompatibility in demand-side were the lack of sufficient knowledge and confronting tools to participate effectively in the electricity markets. Having gradually identified this issue, the Demand-side looked for some confronting tools in order to avoid being placed in this situation.

There are some solutions and confronting tools, proposed so far, to avoid or reduce this problem, these tools are classified into three different categories as follows and shown in Fig. 1:

- Demand Side Management (DSM)Programs
- Purchase Allocation
- Bidding Strategy

After being aware of its lethargy in the early years of restructuring, and the ensuing problems, demand-side started to tackle the imposed problems and promote its role in the market by using these three tools. Using the DSM programs, demand-side managed to amend load profiles as required to increase its profits, reduce the risk of buying from a single producer by diversifying its sources, and create an optimal bidding strategy to achieve higher profits.

This paper reviews and evaluates these tools, which give the demand-side a leverage against supply-side, and carefully examines the works carried out in this field, in order to identify the challenges

* Corresponding author.
E-mail addresses: reza.sharifi@aut.ac.ir (R. Sharifi), fathi@aut.ac.ir (S.H. Fathi), v_vahidinasab@sbu.ac.ir (V. Vahidinasab).

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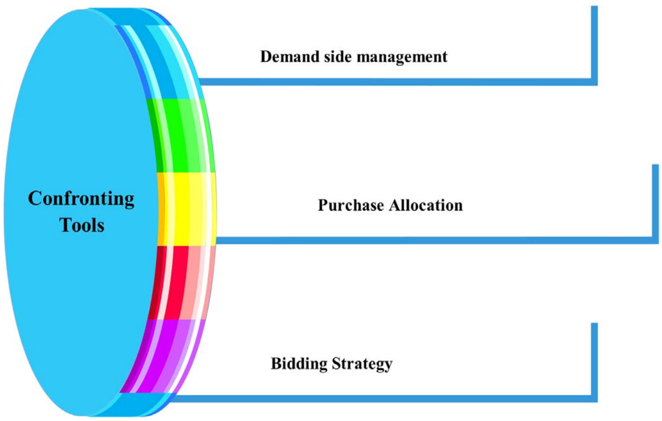

Fig. 1. Confronting tools of Demand-side.

ahead and provide a clear image and framework for future studies.

2. Demand Side Management

As the Demand-side realized the avarice of the Supply-Side, it sought a solution in order to escape from this situation. One of the early strategies of the Demand-side was to adjust its consumption levels according to the price levels, leading to the advent of an extensive discussion, called the Demand Side Management (DSM), in the electricity markets. In most cases, the concept of DSM implies a Supply/Demand-side relationship that results in mutual benefit.

Implementation of DSM plans contains numerous profits for a great number of beneficiaries in the deregulated distribution system. Therefore, this expansion and all-encompassing profitability of such plans cause this option to be constantly considered as one of the substantial research cases, that many actors who are somehow involved in the Demand-side want to investigate different aspects of these plans on their profit and loss.

One of the first papers in the field of DSM is reference [11]. In this article, a framework is provided for the responsibility of a simple consumer to Spot Prices. In reference [12], some aspects of the electricity market, from the perspective of the Demand-side and tools needed by the consumers and retailers to more active and effective participation in electricity markets, are introduced and discussed. According to this reference, if consumers are equipped with the tools for price forecasting and energy storage, they can alter their consumption pattern and transfer their consumption from the times of high energy price to other times. Therefore, in this reference, a decision-making framework, suitable for consumers and significant in terms of the Demand-side, has been presented.

In order for consumers to be able to use the benefits of cheap electric energy at times of low energy price, there must be an interaction between consumers and retailer. In reference [13], a general model of interaction between sellers and consumers in the electricity market has been proposed.

DSM programs are divided into the following techniques [14]:

(1) energy efficiency improvement programs; which reduce the amount of required energy, for instance, double glazed windows, insulation, sealing, installation of light dimmers to control the power consumption, solar water heating systems, etc. [15].
(2) Demand Response (DR)Program; an optional temporary adjustment of consumption as a reaction to the price signal or reliability conditions [16]. In [17], it has been shown that increasing the capabilities of demand-side to react to the electricity price decreases the total costs, as well as alleviating the rate volatility of prices during peak times.

DR programs are divided into two main categories and several subcategories, which are demonstrated in Fig. 2.

In reference [19], the benefits and challenges of DSM plans are discussed in the context of England's Electric System. In reference [20], it is demonstrated that although DSM programs have myriad of benefits, they contain challenges as well, which must be overcome. Of the most significant challenges pointed out in this reference is the creation of appropriate control strategies and reliable framework in such a way as to optimally utilize the generated sources of DSM plans.

Consequently, the biggest problem in the implementation of DSM plans is to establish communication between Supply-Side and Demand-side. With the advent of the Smart Grid, this problem is slightly solved. Smart Grids are known as a controlled electric network, which can transmit electric energy from the producer to the consumers in a clever way [21].

Reference [22], also, have examined the obstacles and challenges ahead of implementation of DSM programs, and has reported the most important challenges in this regard to be as follows:

(1) Consumer Behavior: the uncertainty concerning how consumers react to these programs.
(2) Data issue: inadequate available data due to the lack of experience in this field and novelty of the issue.

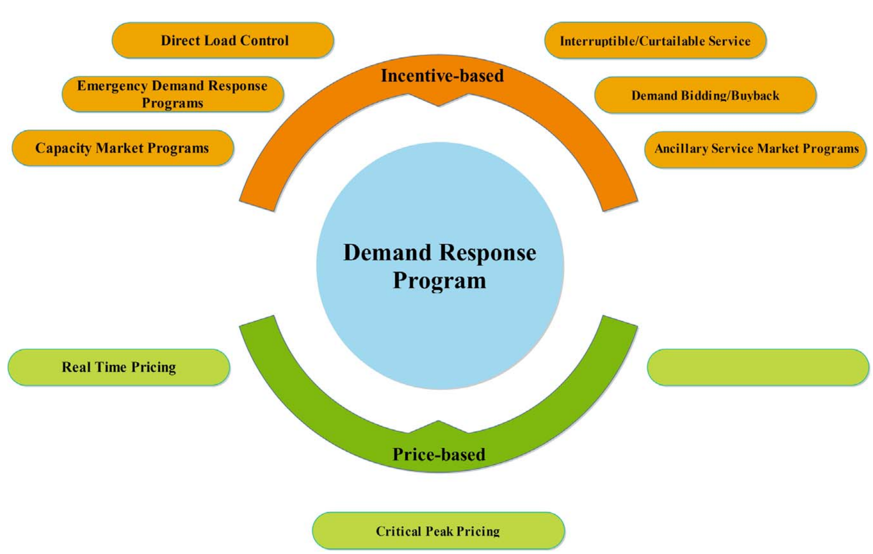

Fig. 2. Categories of Demand Response Programs [18].

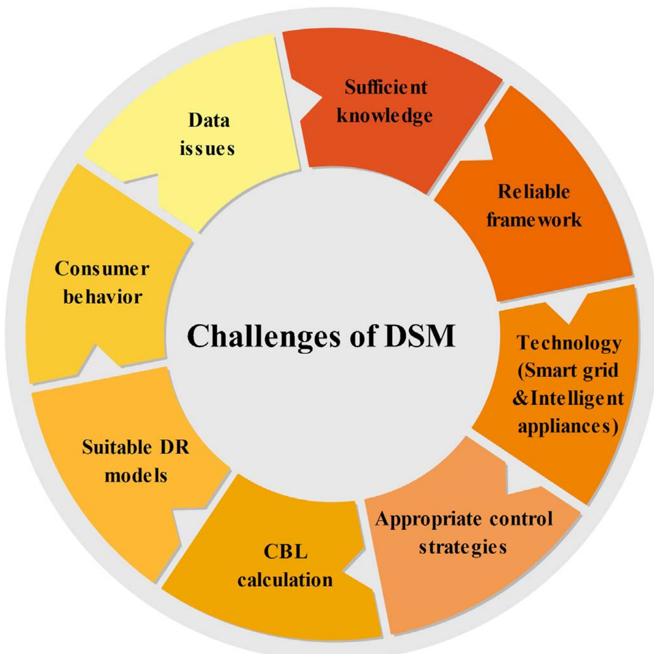

Fig. 3. Most important challenges facing the DSM programs [20–22].

(3) Customer Baseline (CBL) Calculation: CBL calculation is one of the most important steps for assessing the success of DR programs. CBL is the pattern of consumption to be expected in the absence of DR programs, and its accurate calculation is a major achievement in the implementation of DR programs. Reference [23] has shown that inaccurate calculation of CBL will lead to lower customer participation and the mechanism of this effect has been explained. Some of the most important challenges in the implementation of DSM programs are illustrated in Fig. 3.

Among the methods available in price-based DR programs, real-time pricing (RTP) is particularly popular among the market economists [24]. In reference [25], benefits of implementing RTP plan in an electricity market are introduced. Reference [26], By using simple simulations with real parameters, has demonstrated that the amount of profit gained from the implementation of RTP is considerable, even at times when the demand response is low compared with electricity price changes.

Fig. 4 shows the consumer risk/ reward in different price-based DR programs. As shown, with TOU rates offering the lowest risk compared to a RTP but also the lowest reward [27].

Meanwhile, the growing tendency toward the use of renewable energy sources has led to problems such as uncertainty in power source [28]. Renewable resources have lower reliability and controllability than the conventional power plants, which make the networks containing such resources more complex and difficult to operate. These problems can be tackled by several methods, such as, predicting a suitable reserve in the conventional power plants to support renewable resources, providing connections to the nearby alternative grids, and implementation and use of DSM programs. In [29], it has been shown that the use of DSM methods is, by far, the most efficient and cost-effective approach among the mentioned solutions. In [30], after examining the uncertainties in the wind sources, as well as in the demand, a robust optimization approach has been employed to develop a new framework for handling both types of uncertainty and their portrayal over uncertainty sets.

Although DSM programs can effectively result in the reduction of electricity generation prices and bills of the customers, still, in networks with several retailers and consumers, each of them thinks about maximizing its own profit, which is an open and unresolved issue. In reference [31], this issue has been evaluated and, by offering a method based on the Game Theory between retailers and consumers, it has been attempted to maximize all actors' profit.

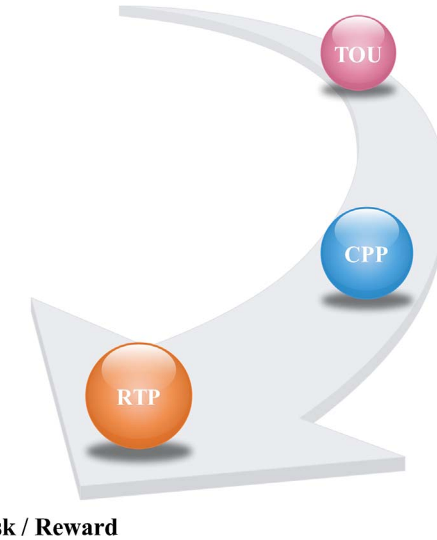

Fig. 4. Consumer risk / reward in different electricity pricing methods.

A Bi-level Stochastic Programming between retailer and consumers has been presented In reference [32]. At Upper Level, the price-taker retailer makes decision based on purchasing energy from the market and then selling it to the customer with the purpose of increasing its profit. In this reference, the retailers consider three methods of RTP, TOU and Flat Rate in order to sell energy to the customers. At Lower Level, the customers alter their consumption pattern according to the offered prices with the purpose of reducing the purchased energy price. The consequent results indicate the priority of RTP to the alternative methods.

There are also other important issues with regard to DSM programs that mostly pertain to industrial and commercial sectors. Implementation of DSM programs in the industrial sector eliminates the need for expensive energy storage, and given the size of demand of this sector, they can be of great use for reducing the price of electricity. In [33], the applications of DR programs in the industrial sector have been thoroughly studied.

The biggest consumer of electric power is the Residential Sector; however, due to its numerous complexities, there are far fewer works regarding applications of DSM programs in the residential sector than for industrial and commercial sectors. In [34], the challenges ahead of implementation of DR programs in the residential sector has been discussed.

In [35], the role of DR programs in the residential sector as envisioned in new markets have been investigated. As shown in Fig. 5, in the residential sector, demand loads are divided into two categories of flexible loads and non-flexible loads. Non-flexible loads, such as lighting, are bound to happen at certain hours and cannot be shifted, but flexible loads can be pushed from one hour to another.

One of the challenges facing the DSM program and especially RTP program in the residential sector is how to create a mechanism in which flexible loads be responsive to changes in power prices of different hours. Although great strides have been made in the provision of equipment and facilities required for such mechanisms, the actual use of these mechanisms is still at an early stage. Authors of [37] have provided a new thermostat design that can respond to price signals, and can be used to make intensive energy appliances, such as heating and cooling systems, responsive. In [38], the benefits of a RTP program in the residential sector at the presence of such price-responsive appliances have been discussed, and the manner in which consumption profile shifts to adapt the new prices and minimize the electricity bill

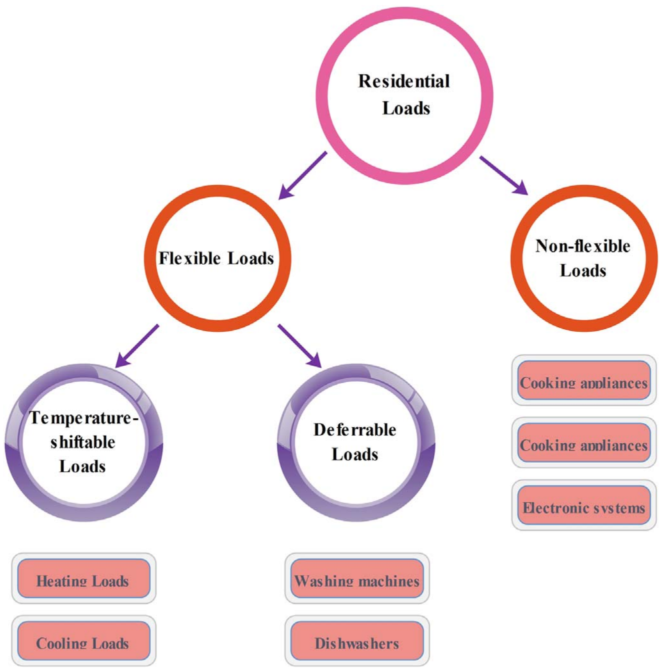

Fig. 5. electricity loads in residential sector [36].

have been demonstrated.

Meanwhile, the advent and development of new electrical loads with high energy storage potential, such as plug-in electric vehicles, have led to new opportunities for the development of DSM programs for the residential sector [39–45].

One of the most important problems in the Residential Sector is the presence of some customers who are not sensitive about the price changes [46]. In other words, consumers behave differently to the electricity price. Accordingly, as shown in Fig. 6, consumers' behaviors can be classified into three general groups[36].

In reference [47], the issue of how flexibility of electricity demand affects on determining electricity price in the market has been discussed. Moreover, various responses of different consumers to electricity price changes have been modeled.

In addition to DSM discussion, the Demand-side, in order to further reduce electric power purchase prices, expanded its aggressive mode and another new discussion named "Purchase Allocation" was

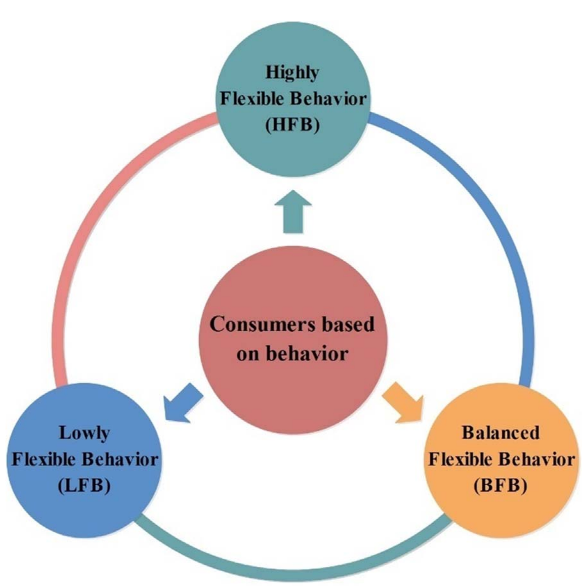

Fig. 6. Consumers' behaviors to DR programs.

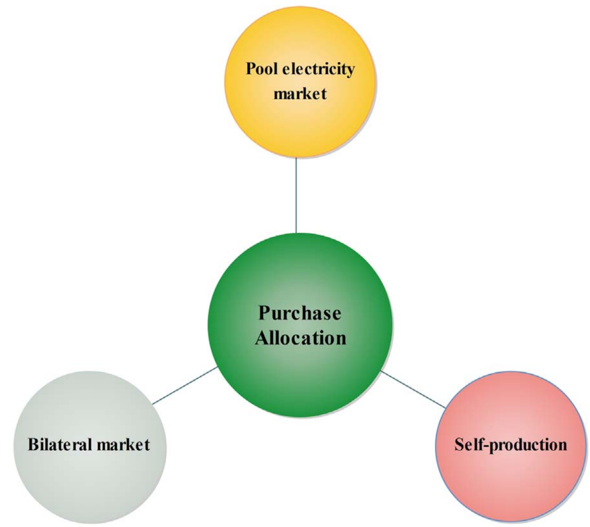

Fig. 7. Classification of Sources of Purchase Allocation.

shaped. In this discussion, retailers and big consumers seek to resolve the problem of how to procure their needs from various sources of electric energy supply in order to increase their profit and decrease risk. This issue is addressed in the following sections of the paper.

3. Purchase allocation

As shown in Fig. 7, the retailer can supply its needs from various sources including bilateral markets, self-productions and pool electricity market [48].

The retailer must decide either to use these sources or not, and determine the share of each of these sources. In consequence, the evaluation of ways of supplying electricity required by retailers from source basket is one of the most substantial measures which must be conducted by a retailer in the competitive market [49]. Performing bilateral contracts reduces the fluctuation risk of pool electricity and if consumers have their self-productions as well, this risk will contain a far greater reduction. Thus, consumers encounter an exchange between bilateral markets, pool and their self-productions. Since prices have numerous uncertainties in different markets based on different conditions, the purchase allocation of each of these markets is an important problem and one of the most substantial difficulties faced by retailers and big consumers.

Since some of the most essential factors in the pool system based market, such as the power demand and price, are ambiguous and uncertain, a stochastic programming problem is faced with. In reference [50], the amount of energy purchase allocation of a big consumer from each electric energy supply has been estimated, while the consumer has its own generating source as well.

Reference [51] has addressed the problem of optimal purchase for electricity markets and pricing method for the intended demand. In this reference, price fluctuations have been considered in the problem of purchase allocation and the nature of Successive changes has been proposed by stochastic models.

In [52], a two-stage problem concerning the optimal size of electricity purchase from bilateral markets and pool electricity market with the objective of minimizing the risk and cost of purchase has been examined. The results of the solution method, proposed in this article, has shown partial success in achieving this objective.

Authors of [53] have developed a hybrid approach for optimal purchase of electricity from all available sources based on binary imperialist competitive algorithm (BICA) and binary particle swarm optimization (BPSO). According to the reported results, this method has a good efficiency in the optimal allocation of purchases. In [54], the mathematical models and mixed-integer stochastic programming have been used to develop a bidding strategy for a retailer purchasing electricity from several sources. In [55], a stochastic model for the purchase of electricity from several sources has been developed. The model provided in this article also reflects the effect of DR program and energy storage systems on the purchase price reduction. In [56], a two-stage decision-making model for purchasing from reserve markets has been developed, and it has been demonstrated that this model can reduce the cost of purchase from this market.

In a competitive electric market, a retailer encounters two major issues. On the one hand, electric energy must be supplied with a variable price from the wholesale market or bilateral contracts (which usually consist of a rate higher than the average price). On the other hand, it faces consumers who have a vague amount of demand and may also have the capability to change their retailer in case of dissatisfaction from the offered prices. In reference [57], this problem has been evaluated and, by providing a suitable stochastic framework, decisions have been adopted on electric energy buying and selling method so as to both maximize the resultant profit and lead to consumer satisfaction as well.

In reference [58], a decision-making framework is proposed for a retailer in an average-term based on a Bi-level Stochastic Programming. These decisions include determining electricity sales price to consumers according to TOU and also determining a plan to allocate purchase from various markets to supply their demand with the objective of risk reduction. In this reference, consumer response to the prices of retailers and also competition of retailers has been considered. In reference [59], a method has been introduced based on Stochastic Programming to optimally solve the problem of electricity purchase for a big consumer in the electricity market. Supply sources include bilateral contracts, self-productions and electricity market based on pool system.

Reference [60] provides a Bi-Level Programming to solve the problem of purchase allocation. The price-taker retailer makes decisions with the purpose of maximizing its profit based on the method of the company in Futures markets and Day-Ahead Markets and also the pricing method to consumers. In this model, numerous uncertain variables have been considered such as Day-Ahead Market prices, consumer demand and prices of other retailer competitors. Here, consumer response to retail price and competition among retailers both have been taken into account in the proposed model. In reference [61], contractual policies relevant to energy purchase of an industrial consumer under the electricity market are investigated. In reference [62], industrial consumer strategies for electric energy purchase in the electricity market are examined.

One other subject, which appeared in the field of Demand-side, was the problem of pricing strategies. In this problem, price-maker retailers and occasionally big consumers seek to extract their Bidding Curves in markets based on pool system with the purpose of enhancing their profit, dealing with the greed of production companies and manipulating market prices to their advantage with the help of bidding strategies.

This subject is addressed in the next section of the article.

4. Bidding strategy

As was seen, in the markets based on pool system, similar to the supply side, the Demand-side also introduces its proposed prices to the pool. According to the microeconomic theory, the best bidding method for each participator in the market with complete competition, is bidding based on marginal costs. However, the presence of some participators, who are capable of affecting market prices, has usually led the electricity markets not to be the type of markets with complete competition. Normally, the price offered by these participators is more than the competitive level or marginal costs. This behavior, the so-called “bidding strategy”, is caused by the power market of this type of participators [63].

In the economics texts, the power market is viewed as one of the market parameters, effective on the commodity price in the market and often for making a profit more than the conditions of perfect competition. Consequently, from this angle, we can immediately deduce the conclusion that the power market is not limited to the producer power alone, but in some conditions, in the Demand-side, some retailers have the power market [64].

It must be noted that the power market is a natural phenomenon based on the rational behavior of market participants, since it is assumed that the market participants are constantly expanding their benefits. Nevertheless, the main point is that every market must have a specific model according to different conditions and, as a result, every market is a designer and creator. It is the duty of the designer to provide the necessary steps in order to prevent creation of this phenomenon. Thus, the need for assessment of removing such cases in deregulated distribution system and price control seems an essential matter [64]. However, despite all these considerations, electricity markets in the whole world still contain some degrees of this power market. In Reference [65], a set of indicators is presented for the measurement of the power market.

In general, participants in the market are divided into two categories based on the power market:

- Price Maker
- Price Taker

The first category refers to the participants who affect market prices, namely have the power market, whereas the second category has no effect on the prices. Thus, in fact, the bidding method of a price-taker participant in the market is a Bidding Problem yet this very problem is a bidding strategy for a price-maker participant [66].

The number of articles presented in the field of bidding strategies in the supply side are numerous and are not comparable with the Demand-side. However, the rate of expansion of papers in this context in the Demand-side, especially in the last few years, indicates the increased interest of researchers in this subject.

According to the economic logic of markets, the suitable economic price at which social welfare is maximum is equal to the Market Clearing Price of electric energy wholesale. In this price, social welfare is the highest. Accurate bidding for the retailers is performed based on costs, customers and competitors. Whenever each of these variables changes, the best price might also change. Therefore, to adopt optimal bidding strategy, it is necessary that the retailer uses an efficient method for bidding in the wholesale market based on different factors. For this purpose, the retailer must understand different bidding methods, their traits, advantages and disadvantages. Therefore, it is necessary to conduct comprehensive researches in this regard [64]. In this context, the number of performed studies is very few.

In reference [67], a framework is introduced for the comprehensive assessment of possible scenarios to implement the bidding mechanism of the Demand-side in the electricity market and evaluate the impact of bidding of the Demand-side in the total production costs, ultimate price and allocated merits between producers and consumers. In reference [68], it has been demonstrated how the bidding of the Demand-side can prevent price jumps in electricity markets. Furthermore, in reference [69], the effects of bidding in markets based on pool system have been evaluated and it has revealed that in case the production programming is based on minimizing the production costs in everyday horizon, then the bidding of the Demand-side can lead to unexpected price jump in the market.

Overall, there are two general methods for the development of bidding strategies:

- Game Theory Based Methods
- Forecasting and Estimation Based Methods

So far, various methods have been presented based on the Game Theory, the most common of which include [70]:

- Bertrand Equilibrium(BE)
- Cournot Equilibrium(CE)
- Supply Function Equilibrium(SFE)
- Stackleberg Equilibrium(SE)
- Conjector Variation (CV) and Conjector SFE Equilibrium

Each of these methods is employed in different competitive levels in the market and is of utmost significance in the evaluation of markets in which the power market exists.

In a complex and severely competitive market, forecasting and assessing demand seems difficult. Retailers can attempt bidding as much as possible according to different methods, after conducting a proper prediction of load, price and or grid to participate in the market. Surely, this bidding depends on numerous factors such as the required load, system conditions, climate conditions, forecasted price, rate of acceptable risk for retailers and the like.

Retailers must have the opportunity and will power to adopt the most optimal bidding strategy in the competitive market. To obtain this goal, after modeling the competitors and choosing the bidding strategy, the retailer should have a simple, fast and accurate software in order to be able to compete in the distribution market and perform the bidding according to conditions, limitations and objectives, using the chosen method. To do this, retailers should transform their bidding strategies with the help of mathematical algorithms into simple and efficient software's, which requires research in this context and use of the experiences of Software experts [64].

In reference [71], a method is proposed for all participators in pool-based electricity markets to construct their bidding strategies. In this reference, it is assumed that both producers and purchasers offer a linear supply/demand function to the market operator. The market operator performs market mechanism with the aim of maximizing the public welfare. Every producer and purchaser chooses coefficients for their supply/demand function whose objective is the expansion of their profit. These coefficients depend on predictions which are considered in relation to other competitors.

In reference [72], a stochastic linear programming model has been proposed to make piecewise-linear bidding curves to offer to the Nord Pool market. In this model, a price maker retailer is introduced which has the duty of supplying electric power for a number of consumers. Moreover, it is assumed that consumers are sensitive to price fluctuations. The purpose of the proposed model is to minimize energy purchase prices from the day-ahead electricity market and the balancing market.

In reference [73], consumers are classified into two groups of Price-Based and Must-Serve in relation to price and, in continuance, the optimal bidding functions of each is deduced.

In reference [74], a model of electricity purchaser in Norway has been provided, which performs bidding in the day-ahead market. The purchasers must arrange their purchase for an indecisive demand. Any kind of difference between purchase and demand must be compensated for in the secondary market after the day-ahead market. In this reference, a Cournot Equilibrium has been considered and assumed that the purchaser has perfect knowledge of generator production function; of course, this model is suitable for today's structures of pool-based electricity markets.

In reference [75], a method is proposed for the extraction of bidding strategies in the day-ahead market for big consumers who supply their demand from the day-ahead market and adjustment market. In this reference, a method has been used for the derivation of bidding curves based on Information Gap Decision Theory (IGDT).

In reference [76], an algorithm is presented based on Monte Carlo to solve the coalition problem of consumers equipped with the demand response plan. This coalition must determine the bidding method in the day-ahead market in which they encounter uncertainties such as prices offered by producers.

In reference [77], a method is presented to determine optimal bidding strategy for a retailer, which provides electricity for its consumers. The purpose of this strategy is to reduce energy purchase prices.

In reference [78], a Dynamic Programming method is proposed in order to make bidding curves for the Demand-side with the aim of enhancing consumer profit and increasing market efficiency for New Zealand. In reference [79], a Stochastic Complementarity Model is suggested to descript the strategic behavior of a big consumer, the obtained results of which make the bidding curves.

In reference [80], a bidding strategy formulation of an electric utility in view of the risk is offered. This utility includes the retail sector which is equipped with the demand response plan. The retail sector is responsible for supplying the demanded electric power. The profit of this utility is obtained by attending the day-ahead market and also selling electric energy to customers through the retail sector. In this paper, IGDT theory has been applied to obtain robust scheduling method against undesirable deviations from market prices. The consequent results refer to desirable effects of the presented strategy and also higher profit by considering the demand response plan.

In [81], a similar work has been carried out for an industrial consumer equipped with cogeneration facilities, and the obtained results have also confirmed the good performance of the proposed method. In [82], a bidding strategy for the Demand-side in the presence of a smart grid has been provided. In this strategy, which has been developed for a day-ahead market, consumers form a consumption profile to maximize their profit depending on the hourly electricity prices and submit it to the retailer one day before the date of consumption. The retailer then sums the submitted load profiles to determine the Demand-side price curves. In [83], a model for optimal purchase by a retailer from pool market has been developed using the bidding strategy and purchase allocation. The presented method is based on a robust optimization approach, and its results provide the retailer with sufficient data to obtain an optimum bidding strategy.

As can be seen, in recent years, several articles have attempted to use combination of methods to challenge the excessive demands of supply-side in electricity markets, and this is a direction that researchers are expected to follow in the coming years.

5. Conclusion

With the advent of deregulated electricity markets, when the Demand-side stretched and bended in compliance with the new environment, it was the supply side that ruled the market and by offering the bidding strategies, the Demand-side asset was captured. This process continued until recently when the Demand-side also sensed and sought a solution.

In the context of electricity markets based on the electricity pool, the main problem is the lower flexibility of Demand-side compared to the supply side. Since most of generation companies can change their rate of production, with less consequences, in order for affecting the prices, yet the Demand-side has less flexibility in consumption reduction for the construction of bidding curves. One of the suitable strategies for the expansion of the demand-side flexibility is to utilize DSM programs. It is suggested that researchers surge their studies in the context of optimization strategies towards the investigation and derivation of bidding curves by implementing DSM discussion; i.e., consider a retailer whose some customers have enthusiasm to participate in DSM programs. The response of customers leads to expansion of flexibility of retailer more than before. In fact, the retailer becomes equipped and can affect on the price, in favor of his benefit, by considering suitable bidding strategies. In this context, a few works have been done, yet they are not considerable and require more attempts.

On the other hand, retailers and big consumers can, for the reduction of their risk, cater their needs from different sources of electricity such as bilateral markets, self-productions and electricity pool. Using each of these sources has its own cons and pros which requires comprehensive studies.

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