Volume XXIII 2020
ISSUE no.1
MBNA Publishing House Constanta 2020

Scientific Bulletin of Naval Academy

SBNA PAPER • OPEN ACCESS

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To cite this article: Simona-Vasilica Oprea and Adela Bâra, Scientific Bulletin of Naval Academy, Vol. XXIII 2020, pg.186-191.

ISSN: 2392-8956; ISSN-L: 1454-864X

doi: 10.21279/1454-864X-20-I1-024

Local market mechanisms survey for peer-to-peer electricity trading on blockchain platform

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Abstract. Blockchain is a promising technology for local trading of the electricity. It has specific components, such as smart contracts, data ledger, consensus, and provides many benefits for both buyers and sellers because they are obtaining/generating electricity at better prices compared with the electricity from the public grid. This practice leads to a better integration of renewable energy sources, increasing the appetite for new local generation sources and storage facilities, transparency and trading opportunities for all market players. Grid operators also benefit from blockchain since the grid loading will be reduced as the grid does not have to transmit or distribute electricity from large power plants located far away from consumption place. In the end, the market players will benefit from reducing the grid loading and alleviating the congestions as onerous investment in grid infrastructure is avoided. In this paper, we will analyse the advantages of different electricity market mechanisms for trading and settlement. Several auction mechanisms such as pay-as-bid, uniform price, generalised second price or Vickrey-Clarke-Groves are taken into account as feasible options for local markets and peer-to-peer trading.

1. Introduction and literature survey

The electricity that traditionally flowed from large power plants to consumers is no longer the only way to supply the demand. On one hand, there is a fast move to distributed generation resources, such as distributed generation and storage facilities. On the other hand, there is a high penetration of modern smart appliances with thermostats, batteries, electric vehicles, etc. that can be controlled to adjust the load curve. These changes lead to new requirements in terms of transactions. In response, utility companies are exploring new business models and technologies to address such challenges. Local producers and consumers could avoid additional costs generated by suppliers and grid operators. This could be done with direct transactions through blockchain platforms that lead to better electricity prices [1].

Blockchain is an incorruptible digital ledger of economic transactions that can be used to record not just financial transactions but virtually everything of value (transactions with Bitcoin or another cryptocurrency) including electricity. It is a system in which a record of electricity transaction is maintained across several computers that are linked in a peer-to-peer (P2P) network. For trading the electricity, market mechanisms are required.

The local electricity markets are emerging technologies that enable P2P electricity trading recorded into data blocks that form a chain that keeps the trace of the transactions. The chain link cannot be altered since each block contains the hash of the previous block.

Before the transaction is concluded, a market mechanism is envisioned for identifying the offers consumers and generators that will actually trade. The consumers or service providers that own storage facilities such as batteries will hourly bid based on the consumption forecast or the previous day consumption if the forecast is not available. Also, the prosumers, generators or service providers will hourly offer their electricity generation that can be locally traded. The two data sets with offers and bids will be day ahead matched with the result of the market clearing. After the auction mechanism is implemented, the data blocks will record the transactions.

Four different types of auction can be carried out to identify the best offers that match the bids. Some of them are very well known and widely implemented, such as Pay-As-Bid (PAB) [2]–[4] or Uniform Price (UP) [5]–[7], while some of them are rarely used by their potential should not be underestimated, such as Generalized Second Price (GSP) [8]–[10]or Vickery-Clarke-Groves (VCG) [11]–[14].

The smart-meters bidirectionally communicate with the consumers sending useful information regarding the hourly cosumption and tariff level (as in Figure 1). The metering records are also sent to the market platform and DSO/supplier. Consumers from a certain area send the bids and preferences including daily budget level, max accepted price, preferece for local generation or renewables, while the prosumers from the same area send the offers. From the market platform, transaction information is sent to the DSO to know the amount of electricity that is required for a certain area. The electricity supplier sends information regarding the electricity price that could be supplied from the public grid. Also, from the market platform, the local market price and transaction information will be sent to the maket players.

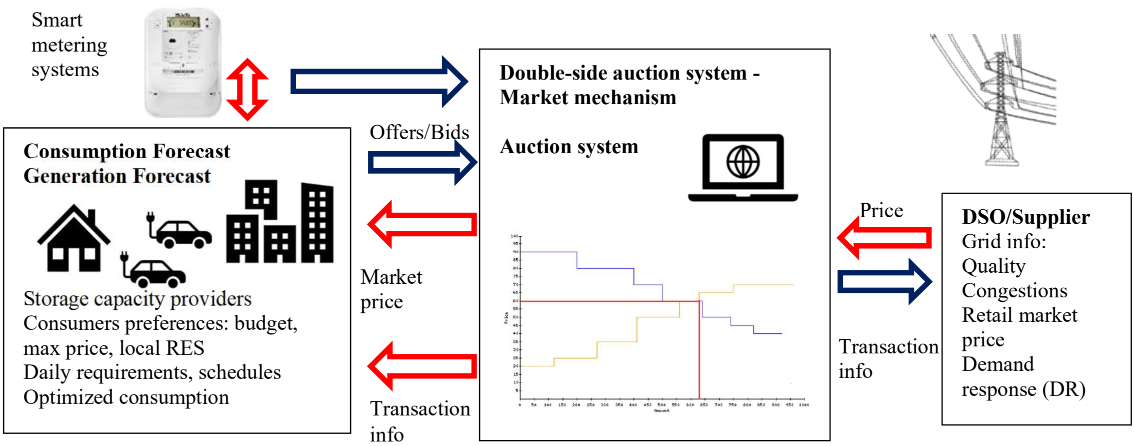

Figure 1. Data flows between local market payers, market platform and DSO/supplier

As shown in [15], the auction systems can be classified into single-side or double-side auction. The single-sided auctions are not suitable for local flexibility markets or local electricity markets since they include multiple prosumers and consumers. Also, [16]–[18] proposed a double-sided auction for local electricity markets.

2. Examples of blockchain trading mechanisms

Several components and barriers (including regulation) of blockchain platform implementation and local electricity markets operation were identified in [19]. The market regulator Energy Market Authority (EMA) of Singapore encouraged innovations, including blockchain [20]. Also, Australian regulators are expected to include blockchain [21].

Examples of pilot or experimental permissioned blockchain applications significant for the power sector include the following: *LO3 Energy* has set Brooklyn Microgrid, which is enabled by blockchain technology to manage local electricity transactions based on bids; Austrian utility Wien Energie is taking part in a blockchain trial focused on energy trading with two other utilities; *Jouliette* (Alliander and Spectral), Verbund and Salzburg AG, etc. revealing the practice of P2P electricity trading; Austrian start-up *Grid Singularity* is experimenting with a decentralized energy exchange platform using blockchain technology; New York-based start-up *Drift* is experimenting with a distributed ledger similar to blockchain for retail energy trading; *Wepower* is building a blockchain-based green energy trading platform.

Also, studies of P2P transactions were developed [1], [18], [22], [23] generating new business models [24], [25].

3. Depiction of auction mechanism types

Different mechanism auction types can be implemented for operating the local electricity markets, including uniform price auction, pay-as-bid auction, generalized second-price as derivate from the second-price or Vickrey auction and Vickrey-Clark-Groves auction.

3.1 Uniform Price auction

The most popular auction mechanisms with relevant implementation are uniform price (UP) and pay-as-bid (PAB) auctions. In auctions, the market clearing price is the most expensive accepted price of a producer or the cheapest accepted price of a consumer. For UP auctions – known as non-discriminatory auctions, as the price is the same for each Wh and the benefits of the prosumers and consumers represent the difference between the market price and the bid or offer price.

PAB, GSP and VCG are known as discriminatory auctions as the price for each Wh differ. Hence, the producers or prosumers that are accepted for trading in PAB auctions will receive the price of their offers. The second price in the merit order that is always lower or equal with the market clearing price will be received for the accepted producers that offers in a GSP auction, while the producers will be rewarded depending on the harm or disturbance they produce to the rest of the market players in a VCG auction.

The UP auction stimulates the producers to offer closer to the costs to increase the chance to be accepted to trade. In case the offer is much higher than the cost, their offer might not be accepted, as a lack of consumption request. This approach is transparent and equally prices the unit of electricity. Over the time, UP and PAB auctions were compared and several studies that analyses pros and cons for each of them were published [6], [26], [27]. Sometimes, the UP auctions are perceived as an overcompensating mechanism, while PAB auctions are encouraging gaming especially when the behaviour of the other market players can be easily foreseen. The UP auctions are well tested and implemented in the reserve markets over the world. UP auction is implemented in Romania for day-ahead market and ancillary service market, while PAB is implemented for balancing market.

3.2. Pay-As-Bid auction

The PAB auctions are also implemented in stock, securities, and other commodities markets. The producers or prosumers are stimulated to make offers below the highest anticipated market clearing price as the accepted offers are paid at their offered price. However, there is a higher risk not to be accepted to trade and the trading opportunity is lost. The consumers' payment could be similar in both auction types or even higher in case of PAB auction because producers offer at higher prices sometimes far from the real costs. The reality showed that the market players have different strategies depending on the auction mechanism [5]. Thus, both UP and PAB auctions are capable of bid inflation.

The change from a UP auction to PAB auction in the wholesale market is analysed under two market structures (competition and monopoly), considering the demand uncertainty. In perfect competition market, there is a balance between efficiency and consumer surplus between the two auction rules, while a change from UP to PAB under monopoly brings a negative impact on profits and a positive impact on consumer surplus [2].

A comparison in electricity pricing mechanisms of UP and PAB pricing is performed in [3]. the actions of a big market player and a small market player are analysed with game and auction theories. The conclusion of the revenue equivalence theorem of the two auction systems (UP and PAB) is invalidated as with PAB pricing led to less revenue than with UP when demand is not elastic. For an elastic demand case, PAB pricing yielded a larger volume of demand being supplied.

EV aggregators could allow a better integration of renewable energy sources. From this point of view, an intraday electricity market and PAB capacity markets [4] are required to allow EV aggregators to contribute and make their offers more efficient.

[6] questioned whether electricity prices increased due to the design of markets mechanisms or auctioning systems pointing out the need to redesign of market rules. The comparison between UP and PAB led to the conclusion that PAB have several serious disadvantages.

An electricity market model based on UP auction mechanism and a small number of producers is envisioned in [7], showing that forward prices can be improved by spot electricity market.

PAB is propose to replace the UP in the electricity markets, the two auctions are compared in [26]. Thus, the PAB auction offered lower market prices and less price volatility.

[27] proposed a two-settlement electricity market with a PAB pricing scheme for balancing, showing the capability of increasing profits compared with UP auction.

3.3 Generalized Second Price Auction

The other two auction mechanism, versions of Vickrey auction: GSP and VCG are less implemented at the electricity market level. An interesting comparison is provided in [8]. GSP is a generalized version of Vickrey auction, considered a natural extension. It is popular for advertising [9], [10], being used by Google, Bing, and Yahoo [28] due to its simplicity and efficacity. In case of market mechanism for local trading, the producer with the highest offer will receive the second-highest offer price in the merit order and the producer with the second highest offer will receive the third-highest offer price so on.

Although, the GSP has not been so far investigated as an auction mechanism for electricity markets, it has a potential to incentive producers to offer prices closer to the cost level as the predictability of other offers is difficult to foreseen [29]. However, [11] proposed a VCG mechanism for a reserve market. Pointing out the advantages of VCG mechanism such as efficiency of the result, avoiding collusion, gaming and shill bidding. Another implementations of VCG mechanism are presented in [12], [13]. Also, for a local electricity market an auction mechanism is built based on VCG auction [14]. A local P2P electricity market is proposed for a better integration of the plug-in hybrid electric vehicles [18].

3.4 Vickrey-Clarke-Grove auction

Another version Vickrey auction is VCG. It charges the producer the disturbance he causes to other producers or prosumers. VCG gives producers incentives to offer their true value. The producer will receive a different price that will be calculated by several formulas starting with the difference between the clearing price and his offer price, known as the result [30]. A new clearing price will be set as if the producer would not exist from which the result will be subtracted.

The two auctions that derive from Vickrey auction implies more calculation and some price limits set especially in case of GSP, are less straightforward and make it more difficult to anticipate the actions of the other market players.

Two variations of VCG mechanism: a multi-level second price (MSP), a progressive second price (PSP) are proposed in [31], analysing the social optimality and incentive compatibility properties of MSP and PSP.

As grid operators and electricity suppliers are excluded from the local electricity markets, they should focus on new business models and reconsider the planning activities [24], [25].

3.5 Comparison among the auction mechanisms

A comparison of the described auction mechanisms is provided in Table 1.

Table 1. Comparison of the four auction mechanisms

	UP	PAB	GSP	VCG
Electricity market implementation	√	√		√
Reserve market implementation	√			√
Discriminatory mechanism		√	√	√
Blockchain	√		√	√
Transparency	√	√	√	
Simplicity	√	√	√	
Market power potential	√	√		
Popularity in other domains	√	√	√	√

The comparison is performed considering several criteria such as electricity/capacity market implementation, discriminatory mechanism, blockchain implementation, transparency, simplicity, market power potential and popularity in other domain.

Acknowledgment: This work was supported by a grant of the Romanian National Authority for Scientific Research and Innovation, CCCDI – UEFISCDI, project title "Multi-layer aggregator solutions to facilitate optimum demand response and grid flexibility", contract number 71/2018, code: COFUND-ERANET-SMARTGRIDPLUS-SMART-MLA-1, within PNCDI III

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