ANALYZING EFFECTIVE COMPETITION IN ENERGY MARKET USING MULTI AGENT MODELLING

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Abstract: Todays, European electricity markets are facing rapid changes which bring some new challenges and make it necessary to modify current market design. One of these changes is continuous increases in electricity generation from renewables. Intermittent supply, decreasing the utilization of conventional generators, and lower market price are some of the consequences of high share of renewables in the market. These effects lead to supply security problem which means lower conventional generation capacity and less backup for intermittent renewable generation in the market.

In this study, we want to discuss on the characteristics of an effective competition in electricity market which can alleviate the supply security problem. The main elements of an effective competition which should be included in future market model are defined as: efficient scarcity prices, active demand side participation, more utilization of storages and optimized guaranteed support policies. To this aim, we have proposed an agent-based framework equipped with game theoretic approaches to analyze this issue in European electricity markets. Based on this proposed model, we will discuss how a well-functioning market with described effective competition can provide right mixture of incentives for investment and enough backup capacity to alleviate supply security problem.

Keywords: Effective Competition, Market Design, Supply Security, Agent-based Modeling

1 Introduction

Energy market structure in most of the European countries is highly influenced by electricity market reform from centralized to more open and competitive structure. The old centrally coordinated monopoly was replaced with competing generators and retailers in unbundled generation, transmission and distribution structure. This reform was intended to encourage more competition among different market participants [1].

Now, European electricity markets are facing rapid changes which bring some new challenges and make it necessary to modify current market design [1]. One of these rapid changes is continuous increases in electricity generation from renewables. Environmental damages form greenhouse gases emission and nuclear wastes, volatile fossil fuel prices, governments' tendency to decrease dependency on oil imports and renewables technological advances are the main drivers for fast growing of renewables [1]. The share of renewables in electricity generation in European Union increased from 12% in 1990 to 21% in 2010 [2]. It is expected that the electricity generation share from new renewables such as wind and solar will be more increased in near future [2].

The rise of renewables' share in electricity generation had some impacts on spot market prices, trading patterns and dispatching of conventional generation. Today, in presence of large amount of intermittent supply from renewables, the major challenge is to maintain a certain level of generation capacity to avoid power shortage situations [3]. In literature, this issue is mentioned as 'generation adequacy', 'missing money' or 'supply security' problem [1]. Besides the ongoing challenges, a priority of EU perspective is to create an integrated European electricity market. Therefore, the solutions for ongoing challenges should be fit in this general perspective [3].

The increasing share of renewables can be seen in almost all of the European electricity markets. This transformation caused many discussions on future market design. A theoretical analysis about supply security problem and insufficient investment in markets is presented in [4], [5] and [6]. They mentioned to this fact that today market structure may not provide sufficient incentives for investment in conventional generation which is necessary to maintain adequate generation capacity in the long term in the market.

Several mechanisms have been introduced to alleviate supply security problem [3], [7], [8], [9]. Among capacity mechanisms, capacity credit mechanism and reliability options are used when a separate capacity market is established in addition to the energy-only market [3]. In these mechanisms, suppliers have to purchase capacity credits or option contracts in capacity market to cover the total forecasted demand plus a reserve margin [3].

Capacity payments and strategic reserves are two other mechanisms which are implemented in energy-only market. Capacity payments are determined by market administrator and are dependent on available capacity and the reserve margin in the market [3]. Higher excess capacity in the market means lower capacity payments. In strategic reserves mechanism, an auction is held on a certain amount of capacity which is withdrawn from regular energy market [3]. This reserve capacity is only dispatched in specific scarcity situations. The price and the amount of acquired reserves are key parameters to measure the effects of this mechanism and inefficient scarcity prices will lead to underinvestment [3].

Agent-based models are popular models to analysis different complex systems [10]. Electricity market is known as a complex system with different types of participants in supply and demand side. As electricity markets moved toward decentralized and more competitive structure, more complex modeling approaches are needed for simulating the market. Because of the importance of electricity market operation, it is necessary to test proposed mechanisms in a risk free simulated environment before applying them to the real world markets [11].

Agent-based framework represents the electricity market with multiple agents act on behalf of market participants with specific goals [11]. As the participants in the market have different strategies and preferences, the agent based model tries to reflect this diversity. Agents improve their decisions by learning both from dynamic market change and collaboration with other agents [11].

The paper is structured as follows: In section 2, the problem is discussed. In section 3, the main elements of effective competition are defined and described. An agent-based model which is equipped with game theoretic approaches is presented in section 4. Section 5 provides a summary and conclusion.

2 Problem Definition

The increasing share of renewables in electricity generation had some impacts on the electricity markets in Europe. The first impact is that supply from some of renewables such as solar and wind is highly fluctuating and intermittent and not reliable enough. This intermittent nature of renewables leads to more uncertainty and less predictability of the generation profile.

The second impact is that the utilization of conventional generators decreases. Most of European electricity markets are energy-only market. In this market, generators get revenue based on the amount of electricity they sell [4]. All generators are sorted according to their marginal cost bids in the merit order curve. Without renewables, base load generators like nuclear and coal plants place at the left side and peak load generators such as gas-fired plants at the right side of the merit order curve [1]. Since electricity generated by renewables has very low marginal cost, it places in left side of merit order curve and shifts the conventional generation to the right side. It means that some of the conventional generators may not be scheduled and pushed out of the market [2]. The third impact is lower market clearing price. Since renewable generation has pushed the supply curve to the right side of merit order curve, the intersection of supply and demand curve will result lower market price.

All above mentioned impacts lead to less utilization and less revenue for conventional generators and cause less incentive for investment in this type of generation. On the other hand, generation from renewables is intermittent and not reliable enough. Then, the market will be faced with supply security problem which means the generation adequacy in the market will not be enough to comply the demand. The main question is that how an effective competition in market can solve this problem and provide enough backup for intermittent generation and a reasonable revenue stream for conventional generators. The purpose of this paper is to provide a discussion and model-based analysis about the main elements of an effective competition which can alleviate supply security issue.

In this study, we want to discuss on a well-functioning energy market which could be able to provide cost recovery for all types of generators to ensure the security of supply. The well-functioning energy market should include active demand side participation, more utilization of storages, optimized policies and efficient scarcity prices to encourage more effective competition among market participants. To this aim, an agent-based framework equipped with game theoretic approaches will be applied for modeling market interactions and analyzing this issue.

3 Effective Competition

As already mentioned, it is necessary to optimize current market structure in order to mitigate current challenges such as supply security problem. To this aim, establishing an effective competition electricity market could be a solution. An effective competition in energy market should have these four elements:

- Efficient scarcity prices
- Active demand side participation
- Utilization of storage facilities

- Optimized guaranteed policies

These improvements will help to elicit the true customers' willingness to pay instead of administratively determined required capacity.

3.1 Efficient Scarcity Prices

Today, prices in European electricity markets are not high enough to recover the fixed costs for exiting power plants and certainly offer no incentive for investment in new power plants [1]. A well-functioning energy market should be able to provide cost recovery for all types of generators to ensure an adequate level of supply security. One way that generators can recover their costs is establishing high market prices during scarcity situations. Since a uniform price auction determines the market price, all generators benefit from high scarcity prices in the case of peak demand.

The scarcity price is an important factor addressing to supply security problem and any deviation from efficient scarcity prices will result less investment. On the one hand, due to the introduction of large amount of renewables in the market, the scarcity situation occurs rarely. On the other hand, as high market prices could result from scarcity situation or abuse of the market power by some of generators, market administrators usually implement a price cap in the market to protect consumers [5]. This price cap is a barrier for conventional generators to use scarcity situation to recover their generation cost. So, it is very important to define the price cap high enough that conventional generators could take benefit from it. Another solution is increasing the frequency and duration of scarcity events. Under market operator control, conventional generators can strategically cooperate with each other to make limited artificial scarcity situations and make profit from high prices. Therefore, an effective scarcity pricing is needed in the market to alleviate supply security problem.

3.2 Active Demand Side Participation

Demand side participation in market plays an essential role to achieve an effective and successful competition in energy market. More effective demand side participation and using price-sensitive interruptible loads can mitigate the supply security issue. Load serving entities, large industrial loads and aggregated residential loads can alter the consumption pattern during less availability of backup capacity in the market. In the case of small residential loads, aggregation of these loads makes their participation in the market more effective. A new market design should consider the expected increase of demand side participation in European energy markets by household, commercial and industrial consumers.

3.3 Utilization of Storage Facilities

Increasing the utilization of energy storages in the market could be a possible solution to alleviate the supply security problem. Storages reduce the necessity for conventional capacities in the market. Also, they bring more flexibility into the market by enhancing the responsiveness of electricity demand to the prices.

3.4 Optimized Guaranteed Policies

Current market developments cause some changes in future regulation and market design which leads to higher investment risks. Also, available barriers for trade in the market, market interventions such as introducing price caps and support scheme for renewables such as dispatch priority increase the future investment risks for conventional generators [12]. So, the support schemes and regulations should be optimized and be applied to the market for a guaranteed long term to shed more light on the market evolution path and reduce future investment risks.

4 Approach

4.1 Modeling Framework

An agent based framework equipped with game theoretic approaches is proposed to study interactions in the electricity market. In this model, different types of agents are equipped with multiple learning capabilities. Agents make their decisions by learning both from dynamic market change and collaboration with other agents. Also, by using game theoretic framework, agents will have the ability of strategic decision making which means that each player will make decision by considering the decisions that other players may make.

The entities competing in this market are a mix of conventional and renewable energy generators as supply side agents, residential, commercial and industrial consumers as demand side agents, aggregators and independent system operator. Aggregators combine smaller participants (as consumers) to enable them to play in the large market. In reality, aggregators are energy retailers or municipal utilities. Based on the model, active demand side agents will learn how to operate effectively in competitive market.

The purpose is modeling the market interactions as close to real world markets. In the competition scenario, real historical data on generation, consumption, capacity and weather information will be used. Based on this proposed model, we will discuss how the well-functioning market with mentioned characteristics of effective competition can provide right mixture of incentives for investment to alleviate supply security problem.

4.2 Method

In this model, market participants such as generators and consumers are represented by their individual set of bidding prices, bidding quantities of electricity, cost and benefit values. Market participants i.e. agents are able to modify their bidding prices and quantity values to get more benefits. To this aim, we use the Roth-Erev reinforcement learning algorithm [13] to model the adaptive behavior of market participants.

Agents have a finite set of available actions which include their bidding price and quantity values. The goal of each agent is to maximize its own individual surplus. The Q-learning algorithm is used as an adaptive learning procedure. The ε-greedy strategy is used as exploration-exploitation process. In ϵ-greedy strategy, agents select the actions with probability P as given in Equation (1). The exploration part of strategy gives the selection probability $1-\epsilon$ to the action which provides the best payoff. The exploitation part of strategy gives the selection probability ϵ/n to all actions. The number of all possible actions is n.

$$P \text{ (Probability of selection)} \begin{cases} 1-\epsilon+\epsilon/\mathrm{n} & \text{Action with best payoff} \\ \epsilon/\mathrm{n} & \text{Other actions} \end{cases} \qquad \text{Equation (1)}$$

Then, we define the reward function for generator agents as presented in Equation (2). R_{a_i} is the reward that each agent gains by taking action a_i. MPC is the market clearing price. q_{a_i} and c_{a_i} are the bidding quantity and bidding price for each generator agent which are determined by taking action a_i.

$$R_{a_i} = MPC - q_{a_i} * c_{a_i} \qquad \text{Equation (2)}$$

The reward function for consumer agents is given in Equation (3). q_{a_i} and d_{a_i} are the bidding quantity and bidding price for each consumer agent which are determined by taking action a_i.

$$R_{a_i} = q_{a_i} * d_i - MPC \qquad \text{Equation (3)}$$

The rule for the update process of the Q-values is given in Equation (4).

$$Q_{a_i}^{new} = (1-\alpha) * Q_{a_i}^{old} + \alpha * R_{a_i} \qquad \text{Equation (4)}$$

Where $Q_{a_i}^{new}$ is the updated Q-value for each agent after each round and by taking action a_i. $Q_{a_i}^{old}$ is the Q-value of the last round and α represents the learning parameter.

The competition runs based on the proposed approach in consecutive rounds and generators and consumers learn how to find the optimal strategy in the market.

5 Conclusion

In this study, we have discussed on a market-based approach which can be utilized in European electricity markets to mitigate supply security problem. The aim is to solve supply security problem by using more intrinsic characteristics of the market participants, instead of administratively determined capacity requirement. To this aim, an effective competition in the market is proposed.

This effective competition is defined by four elements. First element is implementing efficient scarcity prices. Determining high enough price caps and increasing the frequency and duration of scarcity events lead to more efficient scarcity prices. Second element is active demand side participation in the market. Demand side participation adds capacity from demand side and bring more flexibility to the market which can mitigate supply security problem. Third one is more utilization of storage facilities in the market. Storages can play an important role by deploying the stored energy in the market during low generation adequacy situations. Fourth element is reducing the investment risks by establishing optimized guaranteed policies.

Then, we proposed an agent-based framework to analysis the effective competition in the market. During the competition, agents find their own optimal strategies using proposed adaptive learning procedure. As an expected result, this model can be used as an initial model for future energy market structure in Europe.

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