ANALYSIS OF ELECTRICITY MARKET UNDER EXTENSIVE PENETRATION OF RENEWABLE ENERGY WITH MULTI-AGENT REINFORCEMENT LEARNING

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Overview

This paper develops an electricity market model based on a multi-agent model to analyze the impact of the massive introduction of variable renewable energy (VRE) and electricity deregulation on the wholesale electricity market. In Japan, it is necessary to decarbonize the energy sector to achieve the carbon dioxide reduction target (46%) in 2030 and carbon neutrality in 2050, and the amount of VRE introduction is increasing year by year. In addition, the wholesale electricity market was liberalized in 1995, and the retail electricity market was also liberalized in 2016. With this, the amount of electricity traded through the wholesale electricity market (JEPX) has been increasing year by year, so the market mechanism has been introduced to the wholesale electricity trade in Japan. As a result of the combination of the mass introduction of VRE and the deregulation of the electricity market, it is expected that there will be price disruptions and price spikes, as well as an increase in the range of price fluctuations associated with these phenomena. This paper assumes a competitive electricity market model to analyze the conditions and mechanisms of price behavior. The result reveals that the range of price fluctuation becomes larger as the amount of VRE introduction increases, and also reveals that price destruction during VRE generation reduces the sales of VRE operators. As solutions, the paper suggests a cooperative strategy among operators and a market design that does not rely solely on the market mechanism.

Methods

This paper assesses the impact of the mass introduction of VRE and the deregulation of the electricity market on the wholesale electricity market using an electricity market model with multi-agent reinforcement learning. This model conducts a multi-agent simulation in which each electric supplier in the wholesale electricity market is considered as an agent, and analyzes the behavior of the price and each supplier in a competitive electricity market. This model also uses reinforcement learning to model the behavioral mechanism in which participants bid to maximize their profits in a real market. In reinforcement learning, Q-Learning, which is one of the temporal differential learning methods that combine the advantages of Monte Carlo and dynamic programming, was adopted. Fig.1 shows the process of updating the value of action and increasing the probability of selecting a high expected reward by repeating episodes.

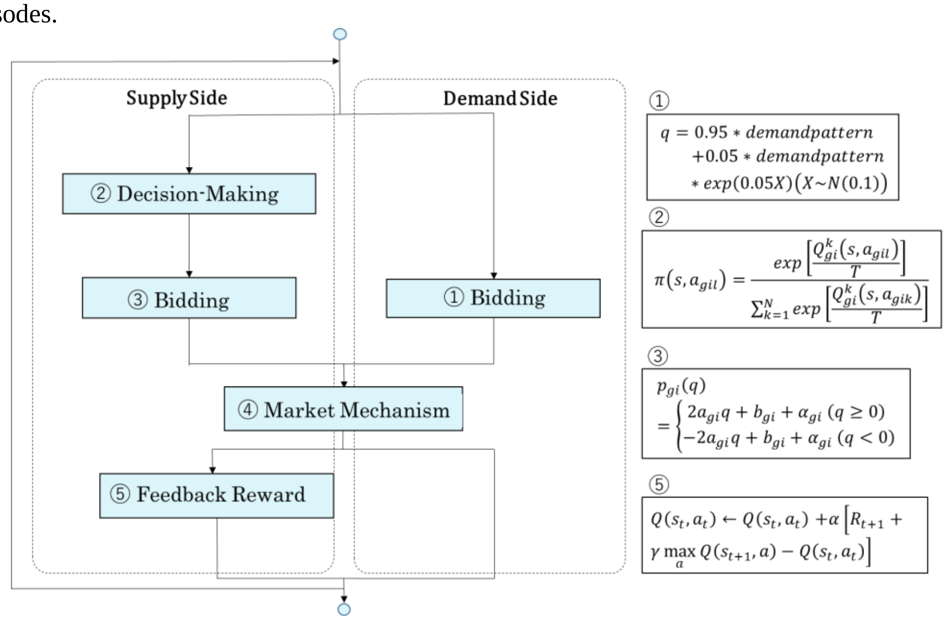

Fig.1 Computational Flow of the Electricity Market Model

Results

First, the analysis shows that in a competitive market, when VRE is introduced in large quantities, the price of electricity falls when the amount of electricity generated by VRE is high (Fig.2). This is because when the amount of electricity generated by VREs exceeds the demand, price competition occurs in which agents bid lower prices to sell all the electricity generated in the market. Also, the decrease in the price when VRE generates high results in lower sales for VRE agents.
Second, the sensitivity analysis revealed that the price fluctuation range and average price tend to increase with the amount of renewable energy introduced, and they tend to decrease with the amount of the capacity of the power storage (battery).

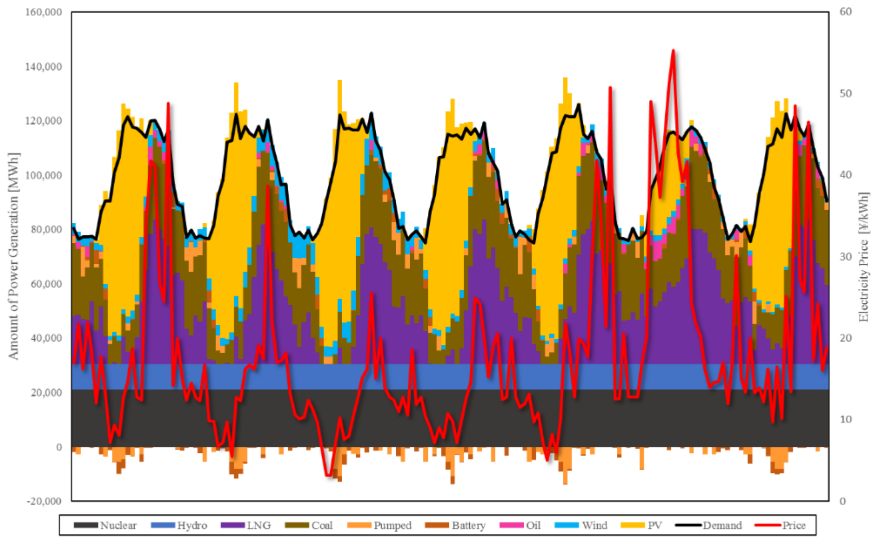

Fig.2 1 week Power Generation Pattern, Demand, and Price

Third, the analysis showed that the cooperation strategy between the VRE agent and the storage battery agent that maximizes the sum of their value function increases the sum of the sales of both agents, and this trend became more pronounced as the amount of VRE introduced increased. These results suggest that uncertainty and risk are reduced for power generation agents in markets where additional interventions such as regulation and symbiosis exist rather than in competitive markets (the limit of electricity deregulation).

Conclusions

In this study, the authors developed an electricity market model and evaluated the impact of the massive introduction of renewable energy and electricity deregulation on the wholesale electricity market. And the result showed the increase in the introduction of renewable energy increases the price fluctuation in the wholesale electricity market, which leads to a decrease in the profits of VRE agents. It also reveals that the cooperation strategy among agents may be effective to prevent the decline in sales.

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