THE INFLUENCE OF ENERGY PROSUMER'S ARBITRAGE STRATEGY ON POWER SYSTEM FLEXIBILITY: A GAME THEORETIC APPROACH

Donghoon Ryu, Hanyang University, Phone +82 2 2220 4479, E-mail: donghoonryu@hanyang.ac.kr
Jinsoo Kim, Hanyang University, Phone +82 2 2220 4479, E-mail: jinsookim@hanyang.ac.kr

Overview

Innovation in the energy sector has been taking place in recent years as countries have recognized the importance of global climate change in substance. The energy prosumers, emerging with these innovations, is a combination of producer and consumer, meaning that people can buy and sell a small amount of energy produced by individuals. Energy prosumer becomes an essential element in future energy trading environment. They deal with small scale power resources such as renewable energy, energy storage system (ESS) and vehicle-to-grid (V2G), which can let them identify arbitrage opportunities. We newly propose a game-theoretic analysis model of prosumers' arbitrage transactions through charge and discharge of ESS including V2G under the seasonal and time-of-use pricing model. Based on seasonal and hourly rate data, we apply different game theories on energy prosumers to compare and analyze how their for-profit behaviors affect the system flexibility. There have been few studies conducted on how the energy prosumer's arbitrage behavior affects the system flexibility which is a crucial problem of power system due to the expansion of renewable energy that has intermittency. It is important to grasp the effects of arbitrage trading of energy prosumers, which are expected to increase in the future, on system flexibility. To derive solutions to maximize the power system flexibility, a comparative study is conducted with a cooperative game and non-cooperative game.

Methods

In the concept of game theory, the cost allocation problem basically must satisfy two properties. One is that all the costs must be distributed to the participating players and not to be left over or exceeded. The other is that the more the player uses, the more the player must pay. Along with these basic conditions, different kinds of solutions have been proposed. A representative solution is Shapley Value, which is defined as

$$\phi(v) = \sum_{S \epsilon 2^{\mathcal{N}}, i \epsilon S} \frac{(|S|-1)!\,(N-|S|)!}{N!}[v(S) - v(S \backslash \{i\})]$$

where $\mathcal{N}$ is the grand coalition, $|S|$ is the number of participants in a coalition. The Shapley Value is a concept that aims to distribute more of the benefits of cooperation to those with higher contributions in a cooperative game. It focuses on the marginal cost of the players in the game. It is calculated by weighted averaging the marginal costs in all possible coalitions of the players. Another famous solution for cooperative games is the nucleolus, denoted as v, which follows

$$\epsilon_j(v) \leq \epsilon_j(x), \forall x \in \mathrm{I}, \forall j \in 2^N - 2$$

where $\epsilon(x) \in \mathbb{R}^{2^N-2}$. Instead of applying a general axiom of fairness to a value function, a fixed characteristic function is used to find an imputation that minimizes the worst inequity. In the inequality, nucleolus v considers how dissatisfied each coalition is with the proposed imputation, and minimizes the total dissatisfaction.

Results

First, we constructed a non-cooperative game, which constitutes the strategy of each energy prosumer, to derive how arbitrage behaviors of the prosumers have an impact on system flexibility. After finding the equilibrium point for the prosumers, we identified the major transaction incentives of energy prosumers applied to the smart grid and the timing of the transactions. This process is presented as a method to maximize power system flexibility. A similar procedure was carried out with a cooperative game to derive maximum system flexibility. The results on the system flexibility based on different game theories are discussed.

Conclusions

This study provides solutions to increase system flexibility in terms of energy prosumer's arbitrage-seeking behavior. Furthermore, we solve the maximization problem of the power system flexibility using the cooperative game and non-cooperative game, which considers the arbitrage strategy of each energy prosumer. The process and results we derived can help policymakers build detailed policies on smart grid that take the arbitrage strategy of participants into consideration.

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