INCENTIVE-BASED DEMAND RESPONSE FOR PROSUMERS IN A GRID-CONNECTED MICROGRID: A GAME THEORETIC APPROACH

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Overview

In recent years, the issue of climate change puts on many governments' agenda the need for reducing greenhouse gases emissions. To this end, the integration of renewable energy (wind, solar) into the energy mix has been encouraged to pave a way for the decarbonation of the electricity industry. In parallel to the massive deployment of renewable energy sources which are intermittent in nature (i.e. variable and uncertain), the increasing energy demands sparkes huge challenges in terms of garanteeing the security of energy supply into the electric system. To deal with this challenge, a new way of bringing flexibility is needed. Conventionally, a widely known approach for balancing the system is based on changing generation sources output to match the rising demand for energy.

With the deployment of Smart Grid (SG) infrastructures (e.g. smart meters and Information and Communication Technology), Demand Response (DR) has attracted more attention from researchers. DR not only plays a key role by enabling more efficient and reliable grid operation but also enables end-users to be more avtively engaged in load management or reducing the peak demand. Specifically, DR can be considered as the ability for end-users to be flexible in response to economic signals (price or reward) that the utility company can use to incentivize consumer to reshape their power usage patterns [2] . Demand response programs are mainly divided into Price-Based Demand Response Programs (PB-DRP) and Incentive-Based Demand Response Programs (IB-DRP).

Recently, there are many studies on Demand Response based on game theoretical approach [1,7, 6]. Specifically, study in [11] uses single-leader/multiple-follower Stackelberg game to investigate the interactions between utility company and a number of residential end-users. Yu and Ho Hong in [11] analyze a DR game based on real time pricing which is aimed to balance supply and demand as well as flatten the aggregated power demand in the whole system. An incentive-based DR based on a two-loop Stackelberg game is applied to capture interactions between a grid operator, multiple service providers, and group customers in order to ensure the system-level dispatch [12]. [4] consider a price-based DR in a retail market and analyze the impacts of integrating renewables and local storage in both a retailer and its customers. Nevertheless, few papers are devoted to the Incentive-based DR program which take into account the impacts of the integration Distributed Enegy Resources (DER) at the consumers permises (i.e. Energy Storage System and Renewable Energy Sources).

In this study, we propose an novel incentive-based DR strategic interaction between a grid operator and a group of residential end-users through a Stackelberg game approach. We first build analytical model, then after run numerical simulations.

The remainder of the paper is organized as follows: Section II introduces the Stackelberg game model. Section III analyzes the proposed game process and provides proof of the existence and uniqueness of the SE. Section IV describes an extension that integrates Energy Storage System (e.g. battery) and Renewable Energy Sources (e.g. solar PV or wind turbine) at each household location and analyses their impact on the DR game model. Section V discusses the simulation results. And finally, Section VI gives conclusions.

Methods

This paper deals with a theoritical analysis based on a non-cooperative game theory approach. A Stackelberg game is used to capture the hierarchical strategic interactions between a grid operatior and a group of located households. The model depicts a Stackelberg game structure as shown in Fig. 1. On the one hand, the grid operator, acting as the leader, moves first by offering incentive to households curtailing load at the requested time event in such a way that it can minimize its total energy cost. On the other hand, rational households, acting as the followers, aim to maximize their welfaire function by considering the trade-off between the economic benefit from load curtailing and the incurred dissatisfaction cost due to load curtailment (e.g. stopping heating device can create discompfort inside the house due to the mismatch between the inside temperature and the desired target temperature). The backward induction procedure will be used to determine the solution of the proposed game, namely the Stackelberg Equilibrium (SE).

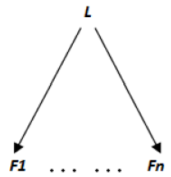

Figure 1: One leader-Multiple followers game structure

Results

The main finding are as follows:

- The existence and uniqueness of Nash equilibrium are proved.
- The Incentive-based DR formulated as a hierarchical game, where the grid operator acts as the leader and the households act as the followers reach an unique equilibrium in which no players can improve their payoffs by unilaterally deviating. The equilibrium is obtained by a backward induction method.
- The impacts of integrating Distributed Enegy Resources (DER) at household location imrpove the reliabity of the system and benefits both the grid operator and households at a certain threshold.
- The numerical simulations results applied in the software Gams (General Algebraic Modeling System, https://www.gams.com/) show that the proposed approach is effective.

Conclusions

This paper proposed an analytical game theory model based on a non-cooperative Stackelberg game between a grid operator and a group of households. Through the backward induction algorithm, one has found the Stackelberg equilibrium after froving the existence of it uniqueness. Morover, the integration on storage can have an influence in the resulting equilibrium outcome of the DR game.
Future work can extend our setting in the following way. One can consider cases when Price-Based DR programs is applied for Home Energy Management Scheduling.

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