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Price setting in the retail electricity market under the Bertrand competition

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Abstract

The paper is concerned with the coordination of interaction between various types of consumers and a power company to manage electricity consumption by using the adverse selection model based on contract theory. There are several power companies competing in the electricity market according to the Bertrand model. A method is proposed for load curve optimization by different types of consumers and a power company. Moreover, the types of consumers are identified and distinguished. The utility functions constructed for them describe the real situation rather well, and allow the implementation of a system of incentives for load curve optimization (load shifting from a peak time of the day by bounded rational consumer). The prices in rates providing a separating equilibrium are determined.

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1. Introduction

The density and non-uniformity of daily load curves of consumers are known to greatly affect the economic indices of electric power systems. Leveling the load curves out by shifting the operation of some electric loads from peak to off-peak time (provided such a shift is admissible in terms of production process of a consumer) allows the electric power system to reduce the demand for generating capacities and current costs of electricity production, transmission and distribution. In this case, the regulation of rate is the most effective mechanism that makes consumer be interested in levelling the daily load curves off [1-3].

The use of market mechanisms and development of information and communication technologies encourage active behavior of another participant in the electricity supply process, i.e. power company, as well. The company becomes capable to encourage consumers to actively manage their electricity consumption [4-6, 7-9, et al] by establishing price options in real time. The interaction between the power company and consumers requires

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coordination of their operation. Until now the potentialities of the coordination have been studied on the basis of mathematical programming methods, including two-stage stochastic programming [10 et al], multi-agent [7,11] and game-theoretic [8, 9, 12-20, 22, 23] approaches.

Considering a great interest of researchers in the game theoretic approaches, we will focus on the game statements of the problems dealing with coordination of interaction between power company and consumers while regulating their operating conditions.

The research [12] can be regarded as a key one, where the best strategy for stimulating consumers to optimize their load curve is developed for the case where power company has incomplete data on consumer actions (this is important in our model). Power company offers a single rate oriented to a total saving of all connected consumers. Each consumer changes their curve and informs the company about it. Solving the problem minimizes the power purchase costs and power demand of all consumers, which decreases the peak load. This is the Nash equilibrium.

Some authors unfold the approach presented in [12] by studying the adjustment of the consumer demand depending on prices in the case of data exchange among all connected consumers, with and without consideration of possible electricity consumption planning [13]. Three algorithms are proposed for different initial conditions. These algorithms are applied to determine the Nash equilibrium. Transformation of their load curve by shifting it from peak time enables each consumer to minimize their power purchase costs. A similar model, which has a different dynamic statement, is presented in [14]. Equilibrium is calculated by repeatedly solving a system of differential equations that maximize consumer utility under the prices specified by supplier.

The problem of load curve optimization taking into account the interaction between power company and consumers is considered in a game-theoretic statement in [15]. The authors of [15] propose an objective function that minimizes peak power consumption and power purchase costs of consumer on-line, which can be done in Smart Grid. The interaction between the company and consumers is formulated as a two-stage game solved by a heuristic method proposed by the authors. Some studies give an in-depth consideration to the real-time analysis mechanism applied by consumers to analyze their load as a “preferred usage time” [16].

In publications, special attention is paid to how the consumer preferences are formed. The utility function depending on both the power purchase costs and the costs of possible inconvenience for consumers becomes the main one. Specific features of the formation of such functions are discussed in [17]. In our research, we construct a model by using various forms of the “convenience” function, depending on consumer type (one of the functions is similar to the one in [15]).

The notion of “active consumer” in [7, 18] is associated with the agents that have some generating capacity or energy storage devices and can use them to regulate their daily load curve. Here there can be various configurations of the game, in [18, 19] the authors present a statement in the form of a Stackelberg game, where leader is represented by power company. The followers (consumers) have their own generation and can sell surplus power to the network in case of shortage, and thus level out the load curve of the company. We compare the strategies of simple competition and Stackelberg competition, and determine the most profitable type of behavior for the company stimulating consumer to optimize their load.

The attractiveness of a consumer stimulation mechanism for peak load reduction for power company is discussed in [20]. Here, the authors propose the use of Groves’ mechanism that enables consumers to determine their true utility itself in the event of imperfect information of the parties.

An analysis of the considered results demonstrates that the interaction between the company and consumers managing their operating conditions is logically formalized on the basis of game theoretic approaches. Moreover, this interaction is not cooperative because the interests of players differ. In the presented paper the problem of daily load curve coordination between a company and active consumers is solved by using one of the game theoretic approaches, i.e. contract theory [21]. The contract theory largely reflects the essence of relationships between players in this problem. Consideration is given to a non-cooperative game, where one party is represented by a power company and the other – by consumers. An important distinction of this research from the

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