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Electricity Pricing Game Mechanism Based on Energy Chemistry Internet of Things

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With the economic and technological development of the society, the reliability and stability of traditional grid power supply have been faced with more challenges. More attention should be paid to the impact on the environment accordingly. Based on the concept of energy chemistry internet of things (EC-IoT), this paper studies the grid structure and electricity market under the background of renewable energy, and also studies the pricing mechanism of electricity according to game theory. Firstly, the characteristics and basic elements of electricity pricing were analysed deeply and the relevant concept model was established, including power grid environment model, electricity market model and power generation model. Then, in view of the characteristics of the electricity pricing problem in the EC-IoT, one power system model was established. Finally, based on the Bayesian Nash equilibrium (BNE) game, the electricity pricing strategy was proposed, by systematically introducing the process of game pricing and the solution to the equilibrium of the electricity price game.

1. Introduction

With the rapid development of society and economy, people’s demand for electricity is also increasing. The traditional power grid faces enormous challenges in terms of power supply reliability, energy efficiency, and stability. Also, another challenge is the increasingly depleted oil and other fossil fuels, and the consequent environmental problems (Kurdi and Alraweshidy, 2008; Demirbaş, 2003). For the sustainable development of mankind, the concept of “Energy Chemistry Internet of Things” using renewable energy to generate electricity and achieve green energy sharing was proposed. Based on the smart power grid, the EC-IoT uses wind energy, solar energy and other renewable energy sources to build a safe, reliable, interactive, and highly efficient power system and then meet the energy demands of social development (Pimentel et al., 1994; Trappe et al., 2015; Jocobsson and Johnson, 2000; Dai et al, 2015).

The EC-IoT emphasizes user participation and the two-way flow of information and energy between users and the network. Therefore, the pricing of electricity is an effective entry point to attract and motivate users. Besides, with the upgrading of the power system industry, power dispatching method of the power industry are also advancing with the times, and the stability of power supply is guaranteed according to the user’s demand response mechanism (Yang et al., 2013; Roscoe and Ault, 2010; Muratori and Rizzoni, 2016; Shafiullah et al., 2016). Under the background of EC-IoT, this paper studies the power grid structure and the electricity pricing mechanism based on game theory.

2. Analysis for electricity pricing of Energy Chemistry Internet of Things

2.1 Characteristics of electricity pricing problem in Energy Chemistry Internet of Things

At present, the rapidly increasing demands for electricity, the depletion of fossil fuels and serious environmental issues play a positive role in promoting the popularization of power supply systems for renewable energy (Wüstenhagen et al., 2007; Barton and Infield, 2004). The establishment of electricity pricing is also the core issue of market reforms. Based on the concept of energy chemistry internet of things, in order to ensure the stability and security of power supply and maximize social benefits in the power grid system of renewable energy, the power supply at this time becomes the problem on the demand side; through

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the price change (Allcott, 2011; Milanovic et al., 2013), the user's demand for electricity can be adjusted. Therefore, the electricity pricing problem based on the concept of energy chemistry internet of things has the following characteristics, as shown in Figure 1.

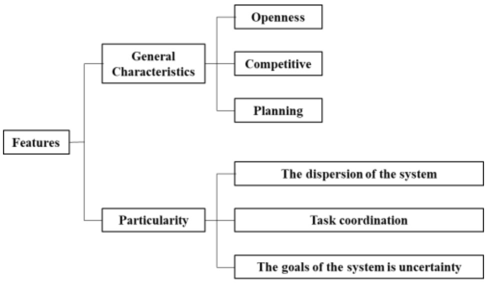


Figure 1: The Characteristics of grid pricing issue

2.2 Key factors of electricity pricing in Energy Chemistry Internet of Things

Under different circumstances, the key factors affecting the pricing of electricity in the EC-IoT are shown in Figure 2:

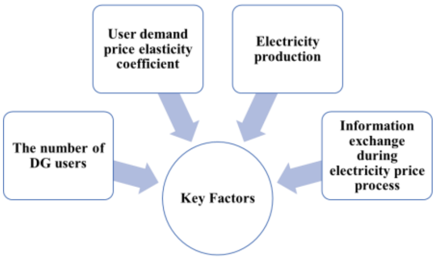
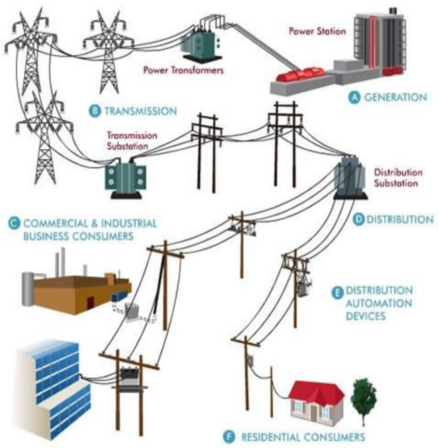


Figure 2: The key factors affecting the price of electricity

3. Elements of the electricity pricing problem for energy chemistry internet of things

3.1 Power grid environment model



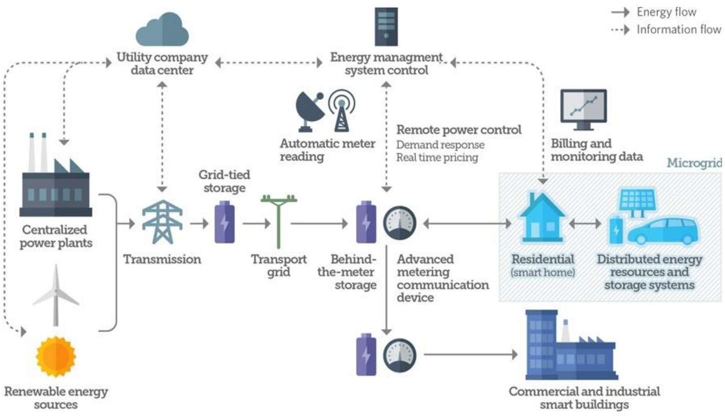


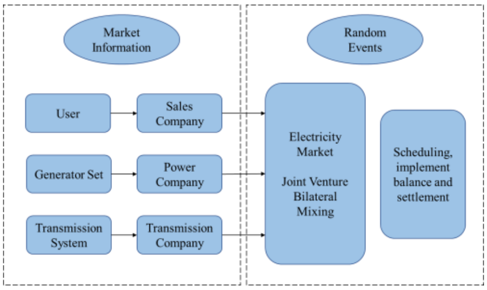
Figure 3: Traditional grid structure

Figure 4: Internet of Things- based renewable energy grid structure

In the traditional power grid system (Figure 3), the power supply company makes centralized control of the electricity, and the user cannot participate in the establishment and transaction process of electricity price. Whereas, the new power grid structure (Figure 4) based on the concept of theEC-IoT can realize the two-way flow of information and energy, enabling the consumers to actively participate in the establishment of electricity prices.

3.2 Electricity market model

Figure 5 shows the basic framework diagram of the simulated electricity market. The electricity market includes various entities such as electricity sales company, power generation company, dispatch system, and users. These entities interact with each other and participate fully in the electricity market strategy and behaviour planning, to jointly determine the development of the electricity market.



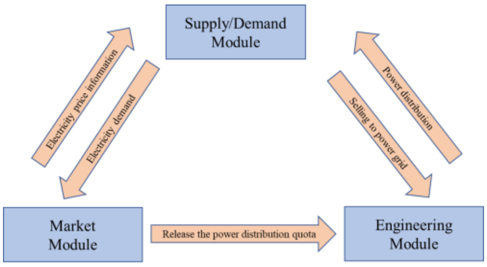


Figure 5: Basic block diagram of electricity market simulation

Figure 6: Electricity market three module diagram

The electricity market can be divided into three modules, and the relationship between them is shown in Figure 6 below. The supply demand module describes the supply and demand relationship of the electricity market, the market module describes the transaction process, and the engineering module describes the abstraction of the physical model of the electricity market. These three are related to each other and jointly determine the pricing of the electricity market.

3.3 Power generation model

At present, all countries are actively adding renewable energy to the power grid, but it is not feasible to completely abandon the original power grid, so most regions still rely on traditional thermal power generation. Of the renewable energy sources, the wind power generation, hydropower generation, and tidal power generation are all subject to geographical restrictions. Now, photovoltaic power generation can be used in a large scale with more mature technology. Its power generation model is shown in the Figure 7 below. Compared to thermal power generation, the initial fixed cost of photovoltaic power generation is relatively higher, but the use cost is decreasing year by year, and it occupies an important position in the future energy network.

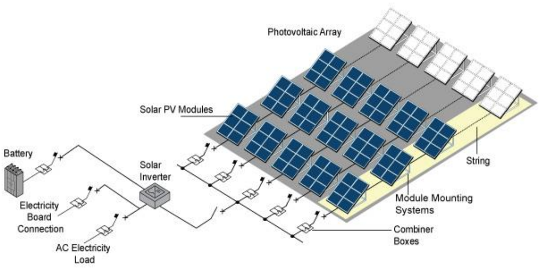


Figure 7: Photovoltaic power system

4. Electricity pricing mechanism based on energy chemistry internet of things

4.1 Game theory

The game is a decision-making method that deals with the relationship between cooperation and competition. This section introduces game theory to determine the electricity pricing mechanism based on the energy chemistry internet of things, and then solves the static incomplete information game between users and suppliers. The concept of the game is the process of selecting the best plan for self-interest based on the competitor's plan. The following table lists the elements of the game and their corresponding effects.

Table 1: The elements of the game

Element	Function
Participant	The main body of game decision
Information	The key to making decision during the game
Action or Strategy	The process of searching for an optimal course of action
Income	Expected benefits obtained by participants
Balance	The most strategic combination of all participants

Based on the elements in Table (1), the game can be divided into the following types of games in terms of different classifications, as shown in Figure 8.

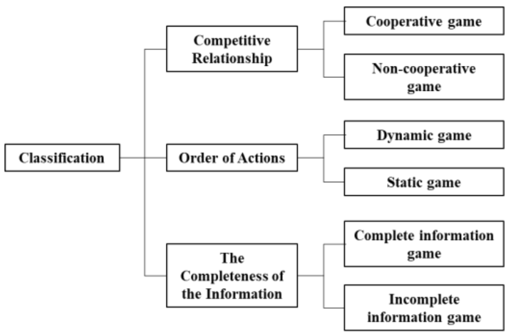


Figure 8: The classification of the game

The author combined the three classifications to obtain four different game types. The game between the user and the power supply provider in Table 2 is an incomplete-information static game - Bayesian Nash equilibrium.

Table 2: Non-cooperative game classification

Action / Information	Static	Dynamic
Complete Information	Nash Equilibrium	Sub-game refining Nash equilibrium
Incomplete Information	Bayesian Nash equilibrium	Refined Bayesian Nash equilibrium

4.2 Establishment of system model

This section establishes one model of the user's demand response in the EC-IoT through the game between the electricity supplier and the user and then determines the electricity price. The users' demand for electricity comes from their own needs on the one hand, and electricity prices on the other. It's hoped that through the establishment of this model, the society's electric power resources can be used fairly and reasonably to achieve the maximization of the total social benefits. From the perspective of the electric power supply company, it is expected that the cost of power supply will be the minimum, and the stable operation of the power grid can be ensured; from the perspective of the user, it's always hoped that priority of use can be given to the users who are most in need of electricity. However, in the actual society, generally, each consumer first considers his/her own interests, so he or she will falsely report information to maximize his/her own interests. Therefore, in order to motivate users to report real information, the reasonable game method should be designed to establish the electricity price.

4.3 Electricity pricing game mechanism

4.3.1 Incomplete-information static game in the process of electricity pricing

In the EC-IoT, the user's electricity demand and service type are all personal information and will not be revealed to other users. However, based on historical data and experience, the user can determine the probability distribution of other user service types. Figure 9 below shows the process of static game with incomplete information.

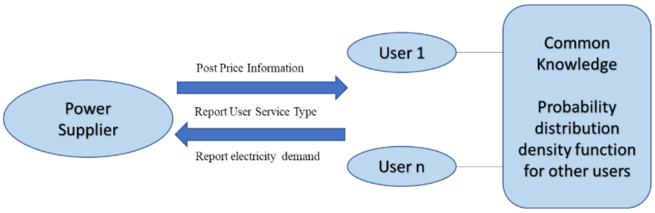


Figure 9: Incomplete information game process in the pricing process

4.3.2 Bayesian Nash equilibrium

The core of the electricity pricing problem is the game between the user and the grid provider, which should seek an equilibrium point. This equilibrium strategy to reach the game equilibrium is called "Bayesian Nash equilibrium", i.e., the optimal strategy for game participators. So, the Bayesian Nash equilibrium is given as:

$$a_i^*(\theta_i) \in \arg max \sum p_i\,(\theta_{-i}/\theta_i) u_i(a_i, a_{-i}^*((\theta_{-i}); \theta_i, \theta_{-i}) \quad (1)$$

where, $a_i^*(\theta_i)$ is the strategic combination of user types, and $p_i(\theta_{-i}/\theta_i)$ is the conditional probability of the user type.
When users report true information, the optimal strategy $a_i^*(\theta_i)$ is shown as:

$$\max \sum_i \,(\mathrm{P}-\mathrm{C})\, Q_{i,\ j+1} P_i \quad (2)$$

where, $Q_{i,\ j+1}$ is the total electricity consumption of the user, P is unit electricity price, and C is the unit purchase cost. The process of solving the equilibrium point is to solve the polynomial optimal solution above.

4.3.3 Establishing process of electricity pricing mechanism

Figure 10: Three-step control methodology

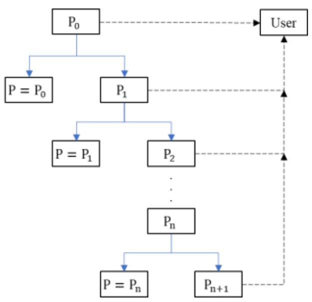


Figure 11: Three-step control methodology

In the power generation system of renewable energy, users are both consumers and producers of electricity. Users can use power generation equipment of renewable energy to produce electricity in their own homes. In addition to meeting their own needs, they can sell surplus electricity on electricity grids. When there is a shortage of electricity in homes under special circumstances, they can purchase electricity from the power grid to ensure the needed for living. Therefore, in the EC-IoT, each user will participate in the establishing process of electricity prices. Based on game theory, this section proposes the power pricing process which consists of three steps as shown in Figure 10 below.
Global prediction: First, the grid company estimates one initial electricity price P_0 according to the historical data of electricity consumption and electricity price, and then publishes the electricity price to the user who estimates the estimated electricity consumption and feeds the data back to the grid company; according to the

reported electricity consumption by the user, the power grid company can calculate its own cost-benefit to determine whether the electricity price is P_0. If it is not, the demand price elasticity coefficient is used to adjust and recalculate a new electricity price, P_1, and publish it again to the user, and the like, as shown in Figure 11, until one equilibrium point of game is obtained.

Individual planning: The pricing of electricity is directly related to the information submitted by users. If users misrepresent personal type information in pursuit of their own interests, this will cause losses to the grid company and not achieve maximum social benefits. Therefore, the relevant incentive mechanism should be established to motivate users to report true information. The incentive constraints include the following two points:

1) The income of the user reporting true information is greater than the income of the false information;

2) The user's income when choosing one certain consumer behavior is greater than its opportunity cost.

If satisfying the above two constraints, the stability of power supply and the rational consumption of users can be ensured.

Real-time control: The system operator monitors the load changes of the entire power grid in real time to prevent drastic changes of the entire power grid system due to climate change or special reasons. The overall situation of the power grid must be observed at any time to ensure the stability of the power supply.

In the establishing process of the actual electricity price, it is necessary to maximize the social benefits, but due to time constraints, number of game iterations is usually selected to determine the final electricity price.

5. Conclusion

Under the background of energy chemistry internet of things, this paper studies the power grid structure and the electricity pricing mechanism based on game theory. The specific findings are as follows:

(1) Based on the concept of EC-IoT, the characteristics and basic elements of the electricity pricing problem were analysed, and the relevant conceptual models were established: grid environment model and electricity market model etc.

(2) In view of the characteristics of power pricing problem in EC-IoT, the electricity pricing strategy based on Bayesian Nash equilibrium game was proposed, and the model establishment; the electricity pricing process and the means to realize the game equilibrium were also introduced in detail.

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