Evolutionary Game Analysis of Demand Response of Power Users' Participation

Mingming Pan1,*, Shiming Tian1, Lifang Wang2, Qian An2 and Lei Wu3

1China Electric Power Research Institute, Beijing 100000, China
2School of Northwestern Polytechnical University, Xi'an 710000, China
3State Grid Tianjin Electric Power Research Institute, Tianjin 300000, China

*Corresponding author e-mail: 331250367@qq.com

Abstract. In the background of smart grid, promoting demand side response actively not only can speed up the transformation and upgrading of China's energy structure, but also further release the vitality of the electricity market. This paper uses the evolutionary game theory, analysis the factors of influencing demand participation of power users and incentive of power companies, build a game model. Then through the calculation, analysis the evolutionary equilibrium strategy. Finally, using MATLAB to simulate and analyze the simulation results.

1. Introduction

With the marketization of electricity, the traditional demand-side management modes such as blackout rationing and orderly use of power [1] are not only costly, inefficient, but also mandatory and inflexible and can not fully adapt to the current situation. Demand-side management model needs innovation to adapt to the process of power marketization. Under the maturing background of smart grid technology, demand-side response becomes a new model of demand-side management. Demand side response is in the electricity market, power users through the power supply side of the price signal or incentive signal to respond to change the behavior, reducing grid load fluctuations to ensure safe, reliable and economical operation [2]. There are mainly two categories of DR: Incentive-Based DR and Price-Based DR. Price-Based DR includes time-of-use price (TOU), real time pricing (RTP), critical peak pricing (CPP) and Incentive-Based DR can be further divided into direct load control (DLC), interruptible load (IL), demand side bidding(DSB), emergency demand response (EDR) and capacity/ancillary service market (CASM) [3].

Power users and power companies play an important roles in the development of demand response. Studying the influencing factors of power users' participation in demand response, analyzing the interest demands of power companies in implementing incentives have great significance in promoting the efficient allocation of power resources, ensuring the safety, stability, Economic operation . At the same time, to explore the relationship between the two and the impact of the two on the development of demand side of power has become an important part of academic research at this stage. Power users as consumers of electric energy and terminals in the electric energy industry, they play a decisive role in the successful implementation of demand response.

Researches on power users' participation in demand response have achieved some achievements both at home and abroad. Hellstrom J [4] (2012) explores the possible reasons behind the jump in Nord Pool...
power prices in the Nordic electricity market through empirical studies, and finds that power user behavior and generation costs are important factors affecting price volatility. Vardakas, JS [5] (2015) classified DR programs and analyzed them based on data from Germany. They found that demand-response reform measures on the sales side alone failed to mobilize the enthusiasm of power users and proposed intelligent power user terminals to enhance Demand-side management efficiency. Liu Jidong et al. [6] (2013) found that there is a great relationship between the user's response to the change of behavior and the incentive of the TOU policy. Wang Beibei [7] (2014) summarized the research progress of user response characteristics in various demand response projects at home and abroad, and classified the influencing factors. Sun Lingling et al. [8] (2016) analyzed the impact of various policy making on user engagement and constructed a model of participation of power users considering policy making. On the basis of herd behavior model, Wu Qike [9] (2016) built a model of herd behavior of power users participating in demand response and based on the social influence and individual subjective tendency, they established a model of demand participation and power users' participation on the basis of herd behavior model, which effectively reflects the condition of users' participation. Zhu Zhenyu, Gao Bingrui [10] (2017) proposed a dynamic analysis model of user engagement in smart electricity based on evolutionary game theory. Dai YeMing [11] (2017) studied the real-time bilateral contract negotiation process of determining the contract volume between the electricity retailer and the large user but of uncertain price, coming to the conclusion of the short-term real-time agreement between the electricity retailer and the big user is mainly determined by the negotiation cost and their respective estimates of each other's prices on real-time. Above research has made much progress on user's participation in demand response. However, most of them have been studied singly from the perspective of the sales side or the power users. However, in the development of the demand response, the incentive mechanism of the power company affects the game strategy of the power user and the power company. On the one hand, power users will decide whether to participate in demand side response according to the incentive measures of power companies. On the other hand, power companies will also adjust the intensity of incentives according to the implementation effect of incentive measures and dynamically adjust the existing measures. The two adjust strategic choice to jointly promote the demand side response in a beneficial direction. This paper attempts to build an evolutionary game model of power users and power companies to analyze the equilibrium point and stability of the model, and study the two choice of strategies. Carry on the different assignment to each parameter, and use MATLAB to carry on the simulation to demonstrate the dynamic game between the power user's participation demand response and the incentive behavior of Power Company.

2. Basic Assumptions and Model Construction
Evolutionary game based on the assumption of bounded rationality which combines the developmental achievements of ecology, sociology, psychology and economics. It is a theory that combines game theory and dynamic evolution to analyze the game player's resource allocation behavior and the strategic choice of the game to deal with the game equilibrium of the bounded rational game player [12]. On the premise of the assumption that all the players in the game are limited rationally, the game player can not find the optimal stability strategy in one game. However, with the continuous adjustment of gamers in each game, after a long period of evolution, the two sides will converge in a certain direction and eventually reach a stable state, that is, the evolutionary stabilization strategy (ESS). Compared with traditional game theory, evolutionary game theory does not require complete rationality or complete information [13], and its conclusion is more realistic and persuasive, which can better predict the behavior of gamers.

The main player of this paper is power users and power companies. As a rational consumer, power users pay attention to personal interests. Based on the principle of maximizing personal interests, power users expect that they will get the most power and power utility under the same power tariff. However, power users cannot fully grasp all the information of the electricity market. They cannot weigh their own economic benefits and power utility at the next moment, which is more important. When they make
decisions, it is difficult to determine whether their interests are maximized. Therefore, power users is only limited rationality. For power companies, their target is different from the power users. Besides the benefits such as power bills, it also needs to consider social benefits: such as, environmental benefits, low-carbon benefits, energy conservation and emission reductions, etc. Therefore, the government will give certain incentives to encourage power companies to promote demand-side responses. However, to advance the demand-side response requires a certain amount of costs, such as the cost of technological innovation, the cost of incentives, etc., and the power company’s incentive is limited for power users. At the same time, because not all users participate in demand response due to incentives, they will also face the risk of failure. Therefore, the power company is also limited rational, and the information obtained is also information.

Power users and power companies are both limited rational and the information obtained is incomplete. Whether power users participate in demand response is the result of game between power users and power companies which is a dynamic process of gradual learning. This paper constructs the evolutionary game model of power users and power companies, studies the interaction between the two, and predicts their decision-making behavior more accurately and truly.

Based on the above theoretical basis, this paper proposes the following Hypothesis:

Hypothesis 1: When power users do not participate in the demand response, their available power utility is $b_1$. When participating in the demand response, the available power utility is reduced and the power loss utility is $b_2$ (for example: For example, during the peak period of power consumption, the factory reduced production and power consumption was reduced, but production was reduced, and electricity utilization was reduced). However, when the power users do not participate in the demand response, they will be affected by the time-of-use or peak-to-valley price, and the power price paid at this time will increase. The added power price is $b_3$.

Hypothesis 2: When the power company implements incentive measures, the power company will give certain economic incentives to the power users, that is, the economic incentive cost that the power companies pay is $m$. At this time, power users participating in demand response can obtain economic incentive income $m$. When the power company does not implement incentive measures, power users cannot obtain incentive income regardless of whether they participate in demand response. Or, in the case of implementing incentive measures, power users who do not participate in demand response cannot obtain incentive income.

Hypothesis 3: When power company chooses to implement incentives, the benefits is $s_1$ (For example, the implementation of incentives will bring positive social and technological benefits, and will be supported by the government. The government will give certain financial subsidies, financial incentives, etc.). In order to implement incentive measures, the implementation costs incurred by power company is $s_2$. Regardless of whether the power users participate in the demand response, as long as the power companies implement incentive policies, they can all obtain the benefits of $s_1$, and they also need to spend the cost of $s_2$.

Hypothesis 4: When the power company chooses not implement incentives, and the power users choose to participate in the active response, the power company can't obtain any extra profits at this time and it does not need to pay any cost. At this time, the power company’s income is zero.
Hypothesis 5: When power users do not participate in demand response, whether the power company implements demand response measures or not, it will require a certain amount of grid stability maintenance costs $s_3$ when the grid operation is unstable in the later period.

The power user's strategy set is (Participate in demand response, Not participate in demand response). The power company’s strategy set is (Incentive, Not Incentive). The proportion of power users participating in demand response is $x$ ($0 \leq x \leq 1$); the proportion of participation in demand response is $1-x$. The possibility of power companies implementing incentives is $y$ ($0 \leq y \leq 1$); the proportion of non-encouragement is $1-y$.

Based on the above assumptions, a revenue matrix for the evolutionary game of power users-power companies is constructed, as shown in Table 1.
Table 1. Gambling Gain Matrix of Power Companies and Power Users

| Game subject | power company                  |
|--------------|-------------------------------|
|              | Incentive($y$) | Not Incentive($1-y$) |
| power use    |                 |                       |
| Participate($x$) | $b_1 - b_2 + m, s_1 - s_2 - m$ | $b_1 - b_2, 0$ |
| Not participate($1-x$) | $b_1 - b_3, s_1 - s_2 - s_3$ | $b_1 - b_3, -s_3$ |

3. Evolutionary Game Analysis

3.1. Stability point analysis

The expected revenue function for power users to participate in demand response is:

$$U_{A1} = y(b_1 - b_2 + m) + (1 - y)(b_1 - b_2) = b_1 - b_2 + my$$

The expected benefit function for power users to choose not to participate in demand response is:

$$U_{A2} = y(b_1 - b_3) + (1 - y)(b_1 - b_3) = b_1 - b_3$$

The average expected income of power users is:

$$\bar{U}_A = x(b_1 - b_2 + my) + (1 - x)(b_1 - b_3)$$

The power user's replication dynamic equation is:

$$F(x) = \frac{dx}{dt} = x(U_{A1} - \bar{U}_A) = x(1 - x)(b_3 - b_2 + my)$$

The expected income function of the power company when choosing to implement incentives is:

$$U_{B1} = x(s_1 - s_2 - m) + (1 - x)(s_1 - s_2 - s_3) = s_1 - s_2 - s_3 + (s_3 - m)x$$

The expected profit function for the power company to choose not to implement incentives is:

$$U_{B2} = (1 - x)(-s_3) = -s_3 + s_3x$$

The average expected return of the power company is:

$$\bar{U}_B = y[s_1 - s_2 - s_3 + (s_3 - m)x] + (1 - y)(-s_3 + s_3x)$$

The power company's replication dynamic equation is:

$$G(y) = \frac{dy}{dt} = y(U_{B1} - \bar{U}_B) = y(1 - y)(s_1 - s_2 - m)$$

According to the copy dynamic equation of power users and power companies, a two-dimensional power system can be obtained:

$$\frac{dx}{dt} = x(U_{A1} - \bar{U}_A) = x(1 - x)(b_3 - b_2 + my)$$
\[
\frac{dy}{dt} = y \left( U_{B1} - U_B \right) = y(1-y)(s_1 - s_2 - mx)
\]

Let \( \frac{dx}{dt} \) and \( \frac{dy}{dt} \) be equal to 0, solving the copy dynamic equations between the power company and the power user, the five partial equilibrium points of the system are (0, 0), (1, 0), (0, 1), (1, 1), (D, E), \( D = \frac{b_2 - b_3}{m}, \) \( E = \frac{s_1 - s_2}{m}. \)

3.2. Evolutionary Stability Strategy Analysis

The local equilibrium point obtained by replicating the dynamic equation is not necessarily the evolutionary stability strategy of the system (ESS), According to Friedman’s [14] method, the stability of the evolution equilibrium can be derived from the local stability analysis of the Jacobian matrix (remember \( J \)) of the system.

\[
J = \begin{bmatrix}
\frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} \\
\frac{\partial G(y)}{\partial x} & \frac{\partial G(y)}{\partial y}
\end{bmatrix}
\]

\[
a_{11} = (1 - 2x)(b_3 - b_2 + my)
a_{12} = x(1 - 2x)m
a_{21} = y(1 - y)(-m)
a_{22} = (1 - 2y)(s_1 - s_2 - mx)
\]

When the above formula meets both of the following conditions:
(1) \( \text{tr}J = a_{11} + a_{22} < 0 \)
(2) \( \text{det}J = a_{11}a_{22} - a_{12}a_{21} > 0 \)
At this point, the equilibrium point of the replication dynamic equation is locally stable, and the equilibrium point is the evolution stability strategy (ESS). Based on this, we can get the values of the five local equilibrium points \( \text{tr}J \) and \( \text{det}J \), as shown in Table 2.

| Stable Points | \( \text{det}J \) | \( \text{tr}J \) |
|---------------|------------------|-----------------|
| (0, 0)        | \( (b_3 - b_2)(s_1 - s_2) \) | \( (b_3 - b_2) + (s_1 - s_2) \) |
| (1, 0)        | \( -(b_3 - b_2)(s_1 - s_2 - m) \) | \( -(b_3 - b_2) + (s_1 - s_2 - m) \) |
| (0, 1)        | \( -(b_3 - b_2 + m)(s_1 - s_2) \) | \( (b_3 - b_2 + m) - (s_1 - s_2) \) |
| (1, 1)        | \( (b_3 - b_2 + m)(s_1 - s_2 - m) \) | \( -(b_3 - b_2 + m) - (s_1 - s_2 - m) \) |
| (D, E)        | A/B              | 0               |

\[
A = (s_1 - s_2)(s_1 - s_2 - m)(b_2 - b_3)(b_3 - b_2 + m)
B = m^2
\]

From the above table, we can see that at the local equilibrium point (D, E), \( \text{tr}J = 0 \). The trace condition of the stable evolution strategy is not satisfied, so the local equilibrium points (D, E) must not be evolution stable strategies. Therefore, only four other local equilibrium points need to be distinguished. When the value of each parameter in the evolution game profit matrix changes, the evolutionary stability strategy will also change accordingly. According to the range of values of each parameter, it will be divided into the following 9 cases.
Case 1: $b_3 > b_2, s_1 > s_2 + m$
Case 2: $b_3 > b_2, s_2 < s_1 < s_2 + m$
Case 3: $b_3 > b_2, s_1 < s_2$
Case 4: $b_2 - m < b_3 < b_2, s_1 > s_2 + m$
Case 5: $b_2 - m < b_3 < b_2, s_2 < s_1 < s_2 + m$
Case 6: $b_2 - m < b_2 - m, s_1 < s_2$
Case 7: $b_3 < b_2 - m, s_1 > s_2 + m$
Case 8: $b_3 < b_2 - m, s_2 < s_1 < s_2 + m$
Case 9: $b_3 < b_2 - m, s_1 < s_2$

Calculate the values of the determinants and traces of the four local equilibrium points for the above 9 cases and analyze their stability, as shown in Table 3.

| Equilibrium point | detJ | trJ | stability | detJ | trJ | stability | detJ | trJ | stability |
|-------------------|------|-----|-----------|------|-----|-----------|------|-----|-----------|
| (0, 0)            | >0   | >0  | N         | >0   | >0  | N         | <0   | N   | Saddle Point |
| (1, 0)            | <0   | N   | Saddle Point | >0   | <0  | ESS       | >0   | <0  | ESS       |
| (0, 1)            | <0   | N   | Saddle Point | <0   | N   | Saddle Point | >0   | >0  | N         |
| (1, 1)            | >0   | <0  | ESS       | <0   | N   | Saddle Point | <0   | N   | Saddle Point |

| Equilibrium point | detJ | trJ | stability | detJ | trJ | stability | detJ | trJ | stability |
|-------------------|------|-----|-----------|------|-----|-----------|------|-----|-----------|
| (0, 0)            | <0   | N   | Saddle Point | <0   | N   | Saddle Point | >0   | <0  | ESS       |
| (1, 0)            | >0   | >0  | N         | <0   | N   | Saddle Point | <0   | N   | Saddle Point |
| (0, 1)            | <0   | N   | Saddle Point | <0   | N   | Saddle Point | >0   | >0  | N         |
| (1, 1)            | >0   | <0  | ESS       | <0   | N   | Saddle Point | <0   | N   | Saddle Point |

Based on the stability analysis of equilibrium points in the above 9 cases, the following conclusions can be obtained:

(1) In case of Case 6 and Case 9, the evolutionary stability strategy of the system is (0, 0)
(2) In case of Case 2 and Case 3, the evolutionary stability strategy of the system is (1, 0)
(3) In case of Case 7 and Case 8, the evolutionary stability strategy of the system is (0, 1)
(4) In case of Case 1 and Case 4, the evolutionary stability strategy of the system is (1, 1)
(5) In the case of Case 5, there is no evolutionary stability strategy in the system.

4. Evolutionary Simulation and Result Analysis

In order to more intuitively reflect the stability of strategic evolution between power users and power companies, and to explore the behavior of power users in participating in demand response, we will assign different parameter indicators and use MATLAB 2017a to simulate the dynamic evolution of the strategy. In the process of marching simulation, this paper selects several sets of different assignment parameters under the condition of determining the value range, the simulation results are consistent. Therefore, under the condition of meeting the range of parameters, the change of parameters will not affect the final evolutionary game result. In addition, this paper also selects different initial conditions, and simulates the dynamic evolution paths of power users and power companies at different initial
selection ratios. It is easy to verify that the initial conditions have no effect on the evolutionary stability results of this paper.

Therefore, this paper will randomly select a group of values that meet the range of values to assign values to each parameter and set the initial conditions to (0.45, 0.45). That is, under the initial conditions, 45% of power users choose to participate in demand response, and 45% of power companies choose to implement incentives. In the figure, the vertical axis represents the proportion of power users participating in the demand response or the power company’s implementation of incentives, and the horizontal axis represents the evolution time axis at intervals of t=1. When the initial conditions are determined, the evolution path of the A and B groups will gradually approach the equilibrium of the system along the non-stationary type of fluctuation.

1) \(b \neq m < b_1 < b_2\) and \(s_1 < s_2\) or \(b_3 < b_2 = m\) and \(s_1 < s_2\)

The evolutionary stability strategy of the system is (0, 0). In this case, assign each parameter individually: ① \(b_2=6, b_3=4, m=3, s_1=4, s_2=7\); ② \(b_2=8, b_3=3, m=3, s_1=4, s_2=7\), The simulation results in both cases are shown in Figure 1 (The red line represents the evolutionary game trend of power companies; the blue line represents the evolutionary game trend of power users).

![Figure 1. Evolutionary simulation of stable point (0, 0)](image)

It can be seen from Figure 1, when ① the power companies choose to motivate the gains less than the implementation costs. Power users do not participate in demand response, and the overpaid power price is less than the loss utility in participating in demand response, the difference between loss utility and return more than participation in demand response. Or, ② the gains from choice of incentives for power companies are less than the cost of implementation, the power user does not participate in the demand response and the overpaid price is less than the difference between the loss utility and the income that participates in the demand response. Power users tend to choose not to participate in demand response, and power companies tend to choose not to implement incentives.

Because at this time, power users pay more attention to the utility of power and the sensitivity to power prices is lower. When the power company gives a smaller positive incentive, it will not play a strong incentive effect. Power users will not easily change their power use behavior because of increased power prices or economic incentives. At this time, because the company’s income is less than the cost, even if incentive subsidies are added, the probability of users responding to the demand response will increase less. At this time, the power company will choose to maintain the status quo. In view of this situation, in the peak period, the power company should first guarantee the user's power supply, prioritize the users who can participate in the demand response, and guide the economic and policy guidance to users with higher priority to actively participate in the demand response.

2) \(b_3 > b_2, s_2 < s_1 < s_2 + m\) or \(b_3 > b_2, s_1 < s_2\)

The evolutionary stability strategy of the system is (1, 0). In this case, assign each parameter individually: ① \(b_2=6, b_3=8, m=3, s_1=6, s_2=4\); ② \(b_2=6, b_3=8, m=3, s_1=4, s_2=7\), The simulation results
in both cases are shown in Figure 2 (The red line represents the evolutionary game trend of power companies; the blue line represents the evolutionary game trend of power users).

![Figure 2. Evolutionary simulation of stable point (1, 0)](image)

As can be seen from Figure 2, ① When the power company chooses incentives, the benefits obtained are greater than the implementation costs and less than the sum of the implementation costs and economic incentive costs. The overpaid power price for power users who do not participate in demand response is greater than the loss utility for participating in demand response. Or, ② Power companies choose incentives, and the benefits they receive are less than the implementation costs. Power users do not participate in the demand response, and the overpaid power price is greater than the loss utility that participates in the demand response. Power users tend to choose to participate in demand response, and power companies tend to choose not to implement incentives. Because the power users do not pay much attention to the power utility at this time, they are more sensitive to the power price, and the increased power price is higher than the power utility brought by these power prices. Give a certain positive incentive, power users will take the initiative to change behavior, participate in demand response. In view of this situation, some load aggregators should be formed to represent the resident users’ participation in the demand response. The load that the power company can cut will increase, and it will also save the user's time.

3) $b_3 < b_2 - m, s_1 > s_2 + m$ or $b_3 < b_2 - m, s_2 < s_1 < s_2 + m$

The evolutionary stability strategy of the system is $(1, 0)$. In this case, assign each parameter individually: ① $b_2 = 8, b_3 = 3, m = 3, s_1 = 7, s_2 = 2$; ② $b_2 = 8, b_3 = 3, m = 3, s_1 = 6, s_2 = 4$. The simulation results in both cases are shown in Figure 3 (The red line represents the evolutionary game trend of power companies; the blue line represents the evolutionary game trend of power users).

![Figure 3. Evolutionary simulation of stable point (0, 1)](image)
As can be seen from Figure 3, (1) When the power company chooses to incentive, the income obtained is greater than the sum of the implementation cost and the economic incentive cost. When power users do not participate in the demand response, the overpaid power price is less than the difference between the loss utility and the income that participates in the demand response. Or, (2) The Power Company chooses incentives, the income obtained is more than the implementation cost, less than the sum of the implementation cost and the economic cost. When the power user does not participate in the demand response, the overpaid price is less than the difference between the loss utility and the income that participate in the demand response. Power users tend to choose not to participate in demand response, and power companies tend to choose to implement incentives.

Because at this time, the power users are more concerned about the utility of power, the sensitivity to power prices is low, and the increased power price is not enough to offset the utility of power. When the positive incentive given is small, the effect of the incentive cannot enable the power user to actively change the power consumption behavior. However, at this time, because the incentive cost that the power company pays is relatively small, and the government subsidy is greater at this time, the implementation of the incentive will bring certain benefits to the power company, and the power company will choose to implement incentive measures. In view of this situation, power companies should increase their incentives to encourage them to participate in demand response.

4) $b_3 > b_2, s_1 > s_2 + m$ or $b_2 - m < b_3 < b_2, s_1 > s_2 + m$

The evolutionary stability strategy of the system is (1, 1). In this case, assign each parameter individually: (1)$b_2 = 6, b_3 = 8, m = 3, s_1 = 7, s_2 = 2$; (2)$b_2 = 6, b_3 = 4, m = 3, s_1 = 7, s_2 = 2$. The simulation results in both cases are shown in Figure 4 (The red line represents the evolutionary game trend of power companies; the blue line represents the evolutionary game trend of power users).

![Figure 4. Evolutionary simulation of stable point (1, 01)](image)

As can be seen from Figure 4, (1) when the power company chooses incentives, the benefits obtained are greater than the sum of the implementation costs and economic incentive costs. Power users who do not participate in the demand response are more likely to pay more than the loss response to participate in the demand response. Or, (2) When the power company chooses incentives, the income obtained is greater than the sum of the implementation cost and the economic incentive cost. When the power users do not participate in the demand response, the overpaid power price is less than the difference between the loss utility and the income in the participation demand response. Power users tend to choose to participate in demand response, and power companies tend to choose to implement incentives. Because at this time, the power users do not pay much attention to the utility of power, and have a higher sensitivity to power prices. The increased power prices are higher than the electricity utilization brought about by these power prices. When given a certain positive incentive, power users will actively change the behavior of power
consumption and participate in demand response. The power company will choose to implement incentives because the benefits it receives are greater than the costs.

5) \( b_3 - m < b_2 < b_3 < s_2 < s_2 + m \)

There is no evolutionary stability strategy in the system. In this case, assign each parameter individually: \( b_2=6, b_3=4, m=3, s_1=6, s_2=4, \) the simulation results in both cases are shown in Figure 5. As can be seen from Figure 5, when the power company chooses incentives, the benefits obtained are greater than the implementation costs and less than the sum of the implementation costs and economic incentive costs. When the power users do not participate in the demand response, the overpaid power price is less than the loss utility in participating in the demand response, and is greater than the difference between the loss utility and the income in the participation demand response. Power companies and power users are in cyclical turmoil and cannot determine their strategies. Power companies need to take certain measures to change this state (The red line represents the evolutionary game trend of power companies; the blue line represents the evolutionary game trend of power users).

![Figure 5. Evolutionary simulation results](image)

5. Conclusion
This paper builds the evolutionary game model of power users and power companies, analyzes the promotion effect of power companies' incentive policies on power users' participation in demand response, and carries out simulation and results analysis. The research results show that the incentive of the power company has a certain effect on promoting the power users' initiative to participate in the demand response, but it is related to the power utility, power price and incentive income of the power users. Power companies should design incentive plans for users with different needs from these three aspects, and promote the active participation of power users in demand response.

The results of this study have implications for formulating relevant demand response policies, advancing the integration of demand response and the electricity market, and enriching and improving demand-side response incentives. Due to limited space, this article will analyze all power users as a whole. However, in actual situations, due to differences in user demand for power, differences in electricity utilization and electricity costs, they cannot be reflected in the same model, and the analysis of demand response to different types of power users will be a further research direction.

Acknowledgments
This study was financially supported by Science and Technology Projects of State Grid Corporation of China fund (Project Name: Research and Application of Multi-load Active Response and Predictive Control Technology for Random Power Supply, Project No. SGTJK00DWSJ1700034); Technical Development Committee Project of China Electric Power Research Institute (Project Name: Research on the Design of Incentive Mechanism for Competitive Power Market, Project No. YDB51201701972).
References

[1] Han Yan-min, Chen Jun, Xiao Ming-wei. Affection analysis of demand response mechanism on power market and users [J]. POWER DSM. 2016, 18 (1): 18-21.

[2] Wu Qiike. Research on conformity influence of power consumers participating in demand response [J]. POWER DSM. 2016, 11 (18): 14-21.

[3] Tao Xiaoma, Zhou Wen. A Review of the Research on Electricity Demand Response [J]. JOURNAL OF BEIJING INSTITUTE OF TECHNOLOGY (SOCIAL SCIENCES EDITION). 2014, 16 (1): 32-40.

[4] Hellstrom Jorgen, Lundgren Jens, Yu Haishan. Why do electricity prices jump? Empirical evidence from the Nordic electricity market [J]. Energy Economics. 2012, 34: 1774-1781.

[5] Vardakas, JS, Zorba, N, Verikoukis, CV. A Survey on Demand Response Programs in Smart Grids: Pricing Methods and Optimization Algorithms [J]. IEEE COMMUNICATIONS SURVEYS AND TUTORIALS. 2015, 17: 152-178.

[6] Wang Beibei. Research on Consumers' Response Characteresics and Ability Under Smart Grid: a Literatures Survey [J]. Proceedings of the CSEE. 2014, 34 (22): 3564-3663.

[7] Zhu Zhenyu, Gao Bingtuan. Research on the participation degree of smart power consumption based on evolutionary game theory [J]. POWER DSM. 2017, 19 (2): 9-13.

[8] Sun Lingling. Research on user engagement in the interruptible load management project [J]. POWER DSM. 2016, 18 (6): 8-13.

[9] Liu Jidong, Han Xueshan, Han Weiji, Zhang Li. Model and Algorithm of Customers’ Responsive Behavior Under Time-of-Use Price [J]. Power System Technology. 2013, 37 (10): 2973-2978.

[10] Dai Yeming, Gao Yan, Gao Hongwei, Jin Feng. Real-time Pricing Contract Bargaining Based on Demand Response in Smart Grid [J]. Chinese Journal of Management Science. 2017, 25 (3): 130-136.

[11] Wu Qiike. Research on conformity influence of power consumers participating in demand response [J]. POWER DSM. 2016, 18 (6): 14-21.

[12] Fan Ruguo. Game Theory [M] Wuhan: Wuhan University Press. 2011: 287-290.

[13] Cao Guohua, Yang Junjie. Research on Evolutionary Game between Consumers' Purchasing Behaviors of New Energy Vehicles Driven by Government Subsidies [J]. Exploration of Economic Issues. 2016, 10: 1-9.

[14] Yu Tao, Liu Changyu. The Analysis of Evolution Gram Model and Simulation between Governments and the Third-Party in ProductQuality Regulation [J]. Chinese Journal of Management Science. 2016, 24 (6): 90-96.