Study on Strategic Equilibria of Tobacco Industry Power Energy Markets in Post-epidemic Era

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This paper aims to solve the strategic balance issues in tobacco industry energy markets in the post-epidemic era, based on the game theory, a strategic equilibrium model for power networks is proposed after evaluating users, power grid company in tobacco industry, and new power entities. By analyzing the claims and interests of relevant transaction subjects, an optimization computation model for tobacco industry power energy markets is constructed, meanwhile the flowchart of finding the Nash optimized solutions is also presented on basis of the genetic algorithm (GA), and the physical meaning of the Nash solutions are explained. The research results can provide some fundamental support and practical suggestions for the related aspects of the power energy markets, along with the economists who study the market design and prediction.

Keywords: tobacco industry; post-epidemic era; energy market; strategic equilibria
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With the continuous rampaging of COVID-19 in the world, its restraints on global economic development and energy market are becoming more and more serious. The balance of global oil and gas supply and demand is broken off, and the demands on oil and gas are rapidly declining, resulting in a rapid decline in the power prices. The spread of the epidemic has become a key reason for restricting energy demand in the future. Many countries and regions in the world have controlled the development of the epidemic by means of blockade and prohibition, which has directly restricted the energy market, and its price trend has accordingly changed.

It was well known that a lot of enormous resources have been devoted to the tobacco industry to attack and refute individual scientific studies. Besides, in order to eliminate the prejudice imposed by people's subconsciousness, the tobacco industry has tried to attempt to manipulate scientific methods and regulatory procedures to make profits for itself industry.[1] It should not be denied that all the efforts done by the tobacco industry may have significant impacts on the power energy markets, specifically in post-epidemic era. However, how could we reasonably model the relationship between the claims and interests of relevant transaction subjects, is also a big challenging issue for the enterprises and the academic circle.

Moreover, the tobacco products may impose some negative or positive effects on the power energy market distributions. For example, a large number of electricity will be consumed in the process of tobacco products, thus the tobacco industry thinks that they contribute too much for the electricity enterprises. At present, the tobacco industry is not willing to acknowledge that they just produce some things that endanger public health.[2] Even they activate and discovery some underlying smokers, they mostly bring more job positions and dedicate to the economics growth, especially in the related transactions parties in the electricity market.

Electricity is unique among all kinds of goods, with the properties of being highly inelastic demand, very limited storage, network traffic determined by Kirchhoff's current law, and transmission restrictions that can isolate consumers from low-cost suppliers. Many regions have released the relaxed the regulation of power generation and handed over the operation of power grid to independent system operators, whose tasks are to collect supply and demand bids, clean up the market by meeting the transmission and security constraints, and then reduce the use of market power. However, the characteristics of power products make the energy market easy to be manipulated. Empirical research shows that these energy markets usually operate in the form of oligopoly, and the participants maximize their profits by adjusting their bidding curve.[3] Based on the comprehensive consideration of power supply strategy, new entities and users' electricity consumption mode of power grid companies, this paper proposes a more competitive market regulation or technology change strategy by modeling the strategic equilibrium in the energy market, and identifies non-competitive behavior by comparing the model with the post market results.

How to deal with the uncertainty of supply and demand and other producers' behavior is one of the key decisions of producers in the energy market. The manufacturers can produce the power of electricity by means of a long-term contract to avoid the underlying risks, or adjust its capacity to the extent that any price can be accepted. The existing research examines the influence of uncertainty on the strategic balance of the spot energy market, especially in the secondary settlement market.[4] However, because of the computational burden of using stochastic model to describe the uncertainty in large networks, these methods may be difficult to solve the problem of balance of energy spot market.

Therefore, on the basis of game Nash equilibrium principle, this paper implements a three-party game modeling method, in which the users, power enterprises and the new entities are mainly involved. The optimization calculation model of game equilibrium solution is first presented, and then the calculation process of equilibrium Nash solution based on genetic algorithm is provided to explain the physical meaning of Nash equilibrium solution. The research results can provide some fundamental support and practical suggestions for the related aspects of the power energy markets, along with the economists who study the market design and prediction.

RELEVANT LITERATURE

A number of game theoretic models of strategic competition are reviewed in literature,[5] and the behavior of oligopoly have been modeled. Three game theoretic models have been used in electricity markets for measuring strategic balance: the model of Cournot has a hypothesis that producers can adjust their output via increasing revenue,[6] the model of Bertrand competition has a hypothesis that producers can adjust price,[7] and the model of Stackelberg leader-follower games has a hypothesis that some firms play a market leader whichhave more ability to determine market trends.[7, 8] Based on the above viewpoints, the Cournot competition which has a good mathematical and computational simplicity, can also predict the market output very well. Therefore, the model of Cournot is used to deal with the model of electricity power market.[6, 9]

However, three game theoretic models are not a panacea in the case of the combination of power market and complex engineering system. Different from most products, the power market is based on a transmission network with tens of thousands of nodes, which has a time output limit for power generation equipment, and is usually composed of a series of sequential markets.[10] In order to solve these problems, some scholars use the engineering model to reflect the technical decisions faced by a single manufacturer.[11-13] These models are usually nonlinear and nonconvex, and it is difficult to model the decision-making of multiple generators with small units.

These random methods can optimize the expected profit, but it is difficult to deal with the modeling uncertainty of hundreds or thousands of nodes. Robust optimization theory and robust game theory provide an alternative method to integrate uncertainty, that is, to seek a solution that still performs well under the "worst case". Although this method can reduce the expected profit of operators relative to their non-robust behavior, it can avoid risks well,[14] because it can ensure that the profits are not affected by uncertainty. These models are also widely used in mathematics, because they do not need any distribution assumptions on random variables and can keep the convexity of optimization problems, thus the efficient solvers can be used to deal with the uncertainty of thousands of nodes.

Robust optimization was previously applied to game theory problems, allowing for uncertainty in modeling in payment matrix or competitor strategy.[15] However, robust optimization is only applicable to specific problems in the operation of power market, such as the combination problem of system operators,[16] the non-strategic investment of users, the non-strategic bidding problem as price acceptor, Stackelberg game strategic equilibrium problem [17] and the strategy balance problem without blocking cost.[18]

Under the premise of the existing exploration results,[19-21] this paper takes Nash equilibrium of game theory as the theoretical guidance, on this basis, the three party game modeling is completed, which involves the parties: one is the power enterprise, two is the user, three is the new entity, and the general expression of its equilibrium solution is given. Then, based on the expression, combined with genetic optimization algorithm, the solving steps of the game equilibrium model are described. Finally, the research conclusions and related prospects based on this model are presented.

GAME MODEL CONSTRUCTION of ENERGY MARKET

This paper analyzes the energy market through multi-party game modeling, which mainly involves three aspects, one is the power enterprise (S_0), assuming that it plays a dominant role in the game, and gives the initial pricing of electric energy in each period; the second is the newly added entity(S_m), which is based on the pricing of electric power enterprises and repricing according to the actual situation of its customers; the third is the user (N), which is based on the demand standard of its own electric energy, and then refers to the pricing of each power supplier, so as to determine the power supplier according to the time period Make a plan for power consumption.

Modeling of Power Grid Users

According to the difference of load characteristics of user equipment, it can be divided into three categories[22]: time adjustable load (A user), electricity adjustable load (B user) and fixed load (C user). The differences of user equipment types are generally reflected by their electricity utility. Customer records usually make corresponding power consumption planning based on the electricity price and load characteristics of equipment.

First, for class A load, there is no limitation factor, and it only needs to meet the relevant standards in the useful working stage. Its power consumption can be expressed by the following formula:

$$\sum_{t_k \in T} q_{n,A}^k = Q_{n,A} \tag{1}$$

where $q_{n,A}^k$represents the power consumption of the load of customer n in t_k period, and below, $q_{n,B}^k$ and $q_{n,C}^k$represent the power consumption of load B and load C in turn. $Q_{n,A}$ is a constant, which represents the power consumption of the equipment to achieve the specified working target.

Second, for class B load, it has some limitations in working period, but it has no limitations or small limitations in power consumption, that is, it must complete power consumption within a given period of time, but its power consumption (power) will not be limited or the limitation is small. Its power consumption can be expressed by the following formula:

$$\sum_{t_k \in T} q_{n,B}^k = \left[Q_{n,B}^{min}, Q_{n,B}^{max}\right], \quad t_k \in T_B \tag{2}$$

where T_B is the set of time intervals of a given time; $Q_{n,B}^{min}$ and $Q_{n,B}^{max}$ are the minimum and maximum power consumption, respectively.

Third, as for class C load, it needs to achieve the specified power consumption target within the specified period of time. There are strict standards in terms of time and power consumption. Its power consumption can be expressed by the following formula:

$$\sum_{i_k \in T} q_{n,C}^{k} = Q_{n,C}, \quad t_k \in T_c \tag{3}$$

where T_c is the set of time intervals of specified time; $Q_{n,C}$ is a constant, which represents the power consumption of the equipment to achieve the given working target.

Modeling of Power Grid Firm

Power grid enterprises provide electricity for customers, and they need customers to pay a certain amount of electricity charges. In addition, they can also require third-party power operators to pay some service charges. Therefore, their income mainly consists of two parts:

(1) All power supply users of power grid companies shall pay for i;

(2) The commission paid by the new entity for the electricity exchange.

If the distribution matrixes corresponding to customers' electricity consumption, payment and income are expressed as Q, Φ and y_0 respectively, then S_0 and y_0 can be easily calculated as

$$y_0 = A_0 \cdot \Phi \cdot B_0 + \lambda \overline{A_0} \cdot Q \cdot \overline{B_0} \tag{4}$$

where λ is the handling charge coefficient; A_0 is the $1 \times n$ order matrix; B_0 is the $k \times k$ order matrix, which represents the customer selection matrix and can calculate the customer payment contained in S_0. Similarly, the power supply can be calculated through $\overline{A_0}$, $\overline{B_0}$, and belongs to the $1 \times k$ order matrix, which can be expressed as

$$y_0 = [y_0^1 y_0^2 \cdots y_0^k] \tag{5}$$

Thus, the income of the power grid company is $Y_0 = \sum_{i=1}^{k} y_0^i$.

In addition to the expenses of power grid enterprises in the process of purchasing equipment, putting into operation and maintenance, the objective loss of power grid is also included. Here, the correlation between the cost and power is expressed by quadratic function, as shown in the following formula:

$$C_0 = a_0 Q_0^2 + b_0 Q_0 + c_0 \tag{6}$$

where C_0 represents the cost of the power grid company; Q_0 represents its power supply; Q_0 can also be calculated by using $A_0 Q B_0$. If $a_0 > 0$, $b_0 \geq 0$ and $c_0 \geq 0$ are the cost coefficients of power enterprises after integrating all the factors.

So far, the income calculation formula of power grid company is formed as follows:

$$W_0 = Y_0 - C_0 \tag{7}$$

Modeling of New Entity

It supplies electricity to customers and requires them to pay electricity charges. The income distribution matrix S_m can be obtained by using the distribution matrix of electricity consumption and payment. For details, please refer to the following formula

$$y_m = A_m \cdot \Phi \cdot B_m \tag{8}$$

where A_m is a $m \times n$ dimensional matrix, B_m is a $k \times k$ dimensional matrix, in which the customer payment contained in S_m can be calculated. The obtained y_m is a $m \times k$ dimensional matrix.

$$y_m = \begin{bmatrix} y_1^1 & y_1^2 & \cdots & y_1^k \\ y_2^1 & y_2^2 & \cdots & y_2^k \\ \vdots & \vdots & & \vdots \\ y_m^1 & y_m^2 & \cdots & y_m^k \end{bmatrix} \tag{9}$$

On this basis, we can obtain the income value corresponding to m, that is $Y_m = \sum_{i=1}^{k} y_m^i$, so its income matrix can be expressed by

$$Y_m = [Y_1 Y_2 \cdots Y_M]^T \tag{10}$$

The cost is often different from that of power grid enterprises. New entity cost is:

$$C_m = [C_1 C_2 \cdots C_M]^T \tag{11}$$

where C_m is the cost of the trader m, Q_m is the power supply of the trader m, and $a_m > 0$, b_m and c_m are different from the relevant coefficients of the power grid enterprise. It can be expressed by

$$C_m = a_\mathrm{m} Q_m^2 + b_m Q_m + c_m \tag{12}$$

ESTABLISHMENT and SOLUTION of GAME EQUILIBRIUM MODEL

This paper constructs a multi-party game model, in which the participants mainly include three aspects: one is customer *N*, the other is power grid enterprise S_0, and the third is new entity S_m. It is assumed that the three parties are rational and expected to achieve their own maximum interests.

As far as user N is concerned, the optimal policy is satisfied with the following formula:

$$Q^* = \arg\max_{q_n^k} W_N \quad (13)$$

$$\text{s.t. } \sum_{t_k \in T} q_{n,A}^k = Q_{n,A} \quad (14)$$

$$\sum_{t_t \in T} q_{n,B}^k = \left[Q_{n,s}^{min}, Q_{n,s}^{max}\right], t_k(B) \in T_B \ (15)$$

$$\sum_{t_k \in T} q_{n,C}^k = Q_{n,C}, t_k(C) \in T_C \ (16)$$

For S0 and Sm, the best strategy should meet the following conditions:

$$p_0^* = \arg\max_{p_0^k} W_0 \quad (17)$$

$$p_m^* = \arg\max_{p_m^k} W_m \quad (18)$$

$$p_0^k \in \left[p_0^{min}, p_0^{max}\right] \quad (19)$$

$$p_m^k \in \left[p_m^{min}, p_m^{max}\right] \quad (20)$$

$$Q_m^k \in \left[Q_m^{min}, Q_m^{max}\right] \quad (21)$$

Based on the definition of Nash equilibrium, all players make decisions independently, and the goal is to maximize their own interests. If their decision-making is determined, they can maximize their own interests and achieve game balance.

Suppose $X = (d_0, d_1, d_2, \cdots, d_m, q_1, q_2, \cdots, q_n)$ is the strategy combination of each player in the game, where d_0 and d_m are the power price planning vectors of grid enterprises and new entities, respectively; and q_n is the power consumption planning vector of customer n.

Therefore,we get X^* as the sufficient and necessary condition for the equilibrium solution of this game: for any participant i (i represents not only customers, but also power supply network enterprises or new entities), each strategy x_i (x_i represents both d_i and q_i) can be expressed by

$$W_i(X^*||x_i) \le W_i(X^*) \ (22)$$

It is noted that in the above (22), $X^*||x_i$ means that the change of its strategy X^* has certain welfare only when participant i in involved in the produce process, while other participants' strategies remain unchanged. Additionally, a three-party non-cooperative game model is described in detail, which is fundamentally related to multi-objective improvement and its optimal solution can be calculated by genetic algorithm. In the process of calculation, the game equilibrium model must be transformed into the corresponding genetic algorithm model.

If D is in the d-dimensional retrieval space, the original population with n individuals can be set as $X = (X_1, X_2, \cdots, X_n)$, and the specific position of the i-th individual in the D-dimensional retrieval space can be expressed by the D-dimensional vector $X_i = (x_{1i}, x_{2i}, \cdots, x_{iD})^T$, which also represents a potential solution of this optimized problem. Through the objective function, the fitness values of different individual positions X_i can be calculated. The velocity of the i-th particle is $V_i = (V_{1i}, V_{2i}, \cdots, V_{iD})^T$, its individual extremum is $J_i = (J_{1i}, J_{2i}, \cdots, J_{iD})^T$, and the population extremum is $J_g = (J_{g1}, J_{g2}, \cdots, J_{gD})^T$. In the process of correlation iteration, the individual can update the corresponding rate and position by using the extreme data of individual and population, that is, the individual can update the corresponding rate and position by the following formula:

$$V_{id}^{k+1} = \omega V_{id}^k + e_1 r_1\left(J_{id}^k - X_{id}^k\right) + e_2 r_2\left(J_{gd}^k - X_{id}^k\right) \ (23)$$

$$X_{id}^{k+1} = X_{id}^k + V_{id}^{k+1} \quad (24)$$

where ω is inertia weight; d=1,2…, D; i=1,2,…, n; the superscript k is the current iteration number; V_{id} is the velocity component of the particle; X_{id} is the particle position component; J_{id} is the individual extremum component; J_{gd} is the group extremum component; $e_1$and e_2 are non-negative constants, which are called acceleration factors; r_1 and r_2 are random numbers distributed in [0, 1] interval.

On the basis of the previous assumption and elaboration of genetic algorithm, the following formula can be used to define the adaptive function as

$$f(X') = \sum_{i=1}^{m+n+1} \max\{W_i(X^*||p_i^k) - W_i(X'), 0\} (25)$$

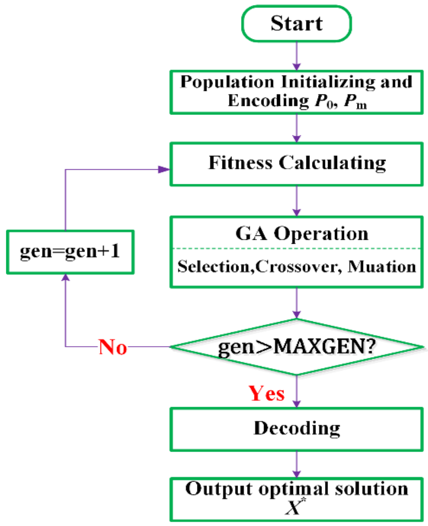

Figure 1
The Flowchart of the Strategic Equilibria for Power Energy Markets Using GA

Based on the definition of Nash equilibrium, if X' is the Nash equilibrium solution at present, then $f(X') = 0$. The flowchart of the strategic equilibria for power energy markets using GA approach is provided in Figure 1.

(1) The initial population is formed, the maximum number of iterations is set to Kmax, and the relevant accuracy standard ε, the relevant parameters in the update formula are set to ω, e and r;

(2) For different individuals, based on the randomly formed strategy P_0 of power supply enterprises, P_0 can obtain the P_m of different particles through random variation, thus forming the solution set $X' = (P_0, P_1, P_2 \ldots, P_n)$ of each individual;

(3) The fitness can be calculated by formula (14), and then the extremum of individual and population, namely, J_i and J_g can be obtained;

(4) Based on the updating formula, the related individuals of different populations are updated, and then the next iteration is carried out;

(5) Once the required number of iterations has reached K_{max}, or the corresponding population extreme J_g can ensure that the fitness function conforms to the relevant accuracy standard ε, indicating that the end of the iteration, the corresponding game equilibrium solution X^* is then obtained.

Conclusion

Currently, the tobacco industry is changing towards a globalization trend, in which the transaction subjects, scientific research and power electricity market are involved in this profit distribution. Hence, it is necessary to draw upon tobacco industry power energy markets strategy in post-epidemic era. The power market is particularly vulnerable to non-competitive behavior, so it is very important to understand the strategic equilibrium, which facilitates better market design and policy-making. The complex structure of power network and many sources of uncertainty in supply and demand make it very important to have scalable tools to study the impact of uncertainty on energy market.

In this paper, a power network strategic equilibrium model is extended to include the robustness to uncertain demand, which reflects the risk aversion behavior of power generation enterprises. The improved robust model remains convex and can be transformed into a larger power supply network. The model can not only describe the optimal bidding strategy or bidding curve of a single producer, but also can provide an effective method to simulate the impact of uncertainty on market results.

To ensure the steady progress of improvement in the competitive market, it is needed to reduce the manufacturer's profit to a certain extent, the correlation analysis shows that, compared with the Nash Cournot equilibrium, the robustness with uncertainty interval consistently increases the profit of power generation enterprises. The impact of robust equilibrium on consumers is negative, because enterprises limit production and lead to price rise, which is similar to the case of collusion. Therefore, the "cost of conservatism" is the reduction of net social benefits of the market.

By modeling the uncertainty of net load (renewable energy must be used for demand reduction), the research results can be used to reflect the supply uncertainty caused by intermittent renewable energy generation. Moreover, the results can also represent the uncertainty of the forward contracts signed by other companies and shrink the surplus supply curve of the spot market. By incorporating robustness into strategic equilibrium, producers, utility companies and regulators can use it to understand the results of real markets.

In future research, a set of tools that can be used to apply convex optimization techniques to larger systems, with hundreds of thousands of participants will be discussed.

This kind of decentralized optimization technology transfers the calculation from the central operator to the local node, and then reaches an agreement on the global optimal solution. This decentralization can be coordinated by servers acting as aggregators, or by peer-to-peer communication between neighbors in the fully decentralized mode. Meanwhile, the follow-up research can focus on the detailed discussion of these models, the introduced security risks, and how to put the example model into practice smoothly.

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