Research on daily energy trading strategy of multi-microgrid on distribution side

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Abstract. This paper studies the energy trading problem between multi-micro grids on the distribution side, and proposes a multi-micro grid energy trading method based on Nash bargaining. The Nash bargaining negotiation breakpoint is the optimal operating cost for direct trading between microgrid operators and distribution operators. This paper considers the cost of over-network transmission of electrical energy in the distribution network, and builds a cooperative game model for multi-microgrid bargaining transactions. Game equilibrium solving problem is solved by genetic algorithm.

1. Introduction

With the maturity of active distribution network technology, more and more microgrids will be connected in the distribution system in the future, which will have a significant impact on the operation and control of the distribution network [1-3]. In the continuous deepening of the electricity market reform in the electricity market, the microgrid with distributed power supply can participate in power trading according to its own interests [4], and enhance the distribution network through diversified market competition and cooperation.

Literature [5] studied the energy trading mode in the micro-grid group and defined the direct energy trading mode between the micro-grids as a loose group mode. Literature [6] proposed a cooperative game model, which is applied in the photovoltaic microgrid group to improve the economic benefits of the microgrid group by promoting the energy interaction between the microgrids. The literature [7-9] studied the game bidding of the microgrid in the distribution market environment, but did not take into account the impact of the grid structure and power flow distribution of the distribution system on the market bidding results. Literature [10] introduced load aggregators in the wholesale market and distribution market, analyzing the dynamic game behavior based on complete information between microgrid, power generation company and load aggregator.

Aiming at the power distribution side power market, considering the power transaction between the microgrid and the distribution network and the multi-microgrid, a Nash bargaining method for multi-microgrid to participate in the recent energy trading is proposed. The disagreement point of Nash bargaining in this paper is the operating cost of microgrid operators and distribution operators when conducting electricity trading. A cooperative game optimization model is used to realize the bargaining problem between multiple MGO(microgrid operator). The constraints of the model in this paper include nonlinear constraints. The solution problem is a high-order non-convex problem, and the artificial intelligence algorithm is more suitable for solving such problems. In this paper, an adaptive genetic algorithm is used to solve the problem.
2. Energy trading market structure

Figure 1 shows the structure of the multi-microgrid day-to-day energy trading market studied in this paper. The market structure consists of a distribution network and a multi-microgrid. The microgrid can either trade directly with the distribution grid or conduct internal bidding transactions with other microgrids. The distribution network gains revenue by selling electricity to the microgrid and collecting network fees. Each microgrid has a large autonomy, and the microgrid sets its operational strategy with the goal of minimizing its own operating costs. The transaction price between the microgrid and the distribution network is determined by the distribution network, and the transaction price between the microgrids is determined by bidding between the microgrids.

![Figure 1. Multi-microgrid power market trading method.](image)

3. The cost model of microgrid without bargaining

The microgrid studied in this paper uses renewable energy (wind power, photovoltaics, etc.) to generate electricity without considering the MGO bargaining transaction. Microgrid operating costs include operating costs of internal energy storage systems, transaction costs between MGO and DNO (Distribution network), and gas turbine fuel costs.

The goal of the microgrid operator is to minimize its own operating costs, and its objective function is as follows:

$$\min C^N_i = \sum_{t=1}^{24} (C_{buy} + C_{sell}) + \sum_{t=1}^{24} (C_{om,k} + C_{dp,k}) + \sum_{t=1}^{24} C_{fuel,i}$$

Equation (1) is the purchase and sale of electricity by microgrids, and the energy storage cost of gas turbines.

Gas turbine cost:

$$C_{fuel,i}(P_{M,i}(t)) = a_i * P_{M,i}(t)^2 + b_i * P_{M,i}(t) + c_i$$

Equation (2) is the output of the gas turbine inside the microgrid, which is a quadratic function of the gas turbine. $a_i, b_i, c_i$ are the coefficients of the second curve of the fuel cost of the i-th controllable unit.

Maintenance costs and depreciation costs of energy storage devices:

$$C_{om,k}(P_k(t)) = K_{om,k}P_k(t)\Delta t$$

Equation (3) is the operation and maintenance cost coefficient of the battery group. $P_{om,k}$ is the rated capacity and $P_{rated,k}$ is the charging and discharging power of the energy storage battery, and $K_{om,k}$ is the unit power operation and maintenance cost coefficient of the battery group. $E_{rated,k}$ is the rated capacity and $P_{rated,k}$ is the charging and discharging power of the energy storage battery.
rated power of the battery pack. $C_{e,k}$ is the present value of the unit capacity and $C_{p,k}$ is the unit power installation cost of the battery pack. $L_{\text{loss},k}$ is the life loss coefficient of the battery pack.

Microgrid purchase cost, sales revenue:

\[
C_{\text{buy}} \left( P_{\text{buy}}(t) \right) = p_{\text{buy}}(t)P_{\text{buy}}(t) \tag{5}
\]

\[
C_{\text{sell}} \left( P_{\text{sell}}(t) \right) = p_{\text{sell}}(t)P_{\text{sell}}(t) \tag{6}
\]

$p_{\text{buy}}(t)$ is the purchase price of electricity from the microgrid to the active distribution network in $t$ period. $p_{\text{sell}}(t)$ is the sell price of electricity from the microgrid to the active distribution network in $t$ period. $P_{\text{buy}}(t)$ is the purchase power of electricity from the microgrid to the active distribution network in $t$ period. $P_{\text{sell}}(t)$ is the sell power of electricity from the microgrid to the active distribution network in $t$ period.

In addition, MGO needs to consider the following constraints in order to achieve the above optimization goals.

Energy storage battery charging and discharging power constraints:

\[
0 \leq P_k(t) \leq P_{\text{max}}(t) \tag{7}
\]

Energy storage battery state of charge constraints:

\[
s_{i}^{\text{min}} \leq s_i^{h} \leq s_{i}^{\text{max}} \tag{8}
\]

The energy storage battery initial state and end state are the same constraints:

\[
s_{i}^{h} = s_{i}^{h+23} \tag{9}
\]

Microgrid internal power balance constraints:

\[
\sum_{l=1}^{K} P_{M,l}(t) + \sum_{k=1}^{K} P_k(t) + P_{\text{buy}}(t) + P_{\text{wind}}(t) - P_{\text{sell}}(t) = 0 \tag{10}
\]

4. The cost model of microgrid including bargaining

In the case of bargaining transactions, the operating costs also need to consider the cost of electric energy transactions and the cost of over-the-network charges. The transaction cost between MGO is as follows:

\[
C_{ij} \left( P_{ij}^hP_{ij}^h \right) = \sum_{t=1}^{24} \sum_{l=1}^{I} P_{ij}^h Q_{ij}^h \tag{11}
\]

$P_{ij}^{m}$ is the transaction power between the microgrids, and $Q_{ij}^{m}$ is the transaction price between the microgrids. When the bargaining transaction is successful, DNO will charge the corresponding network fee according to the line loss brought by the power transmission. The formula for the network fee is as follows:

\[
C_{i}^{\text{net}}(Q_{ij}^h) = \frac{\delta + 1}{2} \sum_{h=1}^{24} \sum_{j=1}^{l} a_{ij}^h Q_{ij}^h + b_{ij}^h Q_{ij}^h \tag{12}
\]

Where $a_{ij}^h$ is the conversion factor of the distribution line loss compensation cost between the microgrid $i$ and $j$; $\delta$ is the cost conversion coefficient of the grid company to measure the line loss investment and operation and maintenance of the overhead line construction. The above is the operating cost function and constraints when considering bargaining transactions between microgrids.

5. Model solution

The microgrid in this paper has independent and independent operational scheduling power and profit margin. He can choose his own trading method. When the microgrid does not participate in the bargaining transaction, the minimum cost function is set to $C_{i}^f$, which is a constant. When the microgrid participates in bargaining, the objective function is set to $C_{i}^f$. The premise of micronet participation in bargaining is that it can strategically select the trading power and trading price between microgrids to further reduce its operating costs, otherwise it will not participate in bargaining.
transactions. The above model solving problem can be summarized as a cooperative game problem, that is, the minimum value of the sum of the operating costs of solving multiple microgrids. Under the following premise:

\[ C_i^c - C_i^n \leq 0 \]  

Performing on the objective function:

\[ \max \prod_{i=1}^{m} (C_i^c - C_i^n) \]  

The solution strategy for this problem is the transaction power and transaction price between the microgrids.

\[ U_i^c = C_i^n + C_i^{net} \]  

The solution to the above problem can be translated into:

\[ \min \sum_{i=1}^{m} U_i^c \]  

The article uses genetic algorithm to solve. The Figure 2 following is the genetic algorithm solution flow chart.

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Figure 2. Genetic algorithm solution flow chart.

6. Case analysis
In the MATLAB2016a compiler environment, this paper simulates the power market trading on the power distribution side. The basic data of the three microgrids are as follows. The microgrid has an
energy storage capacity of 300kw, a maximum charge and discharge power of 100kw, and an operating capacity range of [30kW, 300kW]. Table 1 is the time-of-use tariff as follows:

| Trading mode | MG1          | Time slot          |
|--------------|--------------|--------------------|
| Sales price  | Feng: 1.256  | 9-12; 17-22        |
| Sales price  | Ping: 0.836  | 8-9; 12-17         |
| Sales price  | Gu: 0.512    | 0-8; 23-24         |
| On-grid price| 0.347        | 0-24               |

The renewable energy generation and load requirements in the microgrid are shown in the Figure 3 and Figure 4 below.

**Figure 3.** New energy generation power.

**Figure 4.** Microgrid load power.

The simulation results of MGO bargaining power are as follows:
Figure 5. Transaction power between microgrids.

It can be seen from Figure 5 that under the equilibrium conditions of the market, MGO can realize the purchase and sale of electric energy in different time periods through bargaining transactions. The most traded is the electricity sold by the microgrid 3 to the microgrid 2.

Figure 6. Transaction price between microgrids.

As can be seen from the Figure 6, the price of electricity for bargaining transactions is higher than the repurchase price of the grid company at each time period, which is lower than the sales price of the grid company. Therefore, the sale of electricity MGO can obtain more electricity sales profits through bargaining transactions; purchase MGO can reduce the purchase cost of electricity through bargaining transactions.

The Figure 7 below shows the simulation results of the energy trading volume between the microgrid and the distribution network in the case of MGO participating in bargaining transactions and not participating in bargaining transactions. The above phenomenon indicates that participation in bargaining transactions. Each MGO reduces its energy trade with DNO.
Further analyze the impact of bargaining transactions on the operating costs of microgrids. The optimal total operating cost of the microgrid system before bargaining is 32496.0 yuan. After the bargaining price is 32388.65488 yuan.

7. Conclusions
In this paper, the optimal operating cost of direct trading between MGO and DNO is used as the negotiation breakpoint of Nash bargaining, and a cooperative game model of multi-microgrid bargaining is constructed. The problem of minimizing the operating cost of microgrid under the two situations of MGO and DNO direct transaction and mutual bargaining between multiple microgrids is analyzed. The simulation analysis of three microgrid optimization operations in the actual system is carried out to verify the proposed method. Reduce the effectiveness of microgrid operating costs.

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