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Coordinated Development Based Grid-Source-load Collaborative Planning Method of Uncertainty and Multi-agent Game

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Abstract. When planning the power grid, it is necessary to obtain the optimal decision scheme according to the market behavior of different stakeholders. In this paper, the virtual game player "nature" is introduced to realize the deep integration of game theory and robust optimization, and a source network load collaborative planning method considering uncertainty and multi-agent game is proposed. Firstly, the planning decision-making models of different stakeholders of DG investment operators, power grid investment operators and power users are constructed respectively; then, the static game behavior between distributed generation (DG) investment operators and power grid investment operators is analyzed according to the transmission relationship of the three; at the same time, robust optimization is used to deal with DG. In this paper, we introduce the virtual game player "nature" to study the dynamic game behavior between the virtual game player and the power grid investment operator. On this basis, the dynamic static joint game planning model is proposed.

1 Introduction

At present, some scholars have begun to study the game problem in distribution network planning [1-4]. The game theory is applied to distribution network planning for the first time, and the optimal location and capacity of DG are realized through the game among investment cost, line loss and voltage quality [1]. Based on the complete information dynamic game theory, taking photovoltaic, energy storage and power grid as game participants, the game relationship among the three parties under the market environment was analyzed, and the coordinated planning model of optical storage network was established [2]. According to the possible alliance relationship between wind power generation, photovoltaic power generation and energy storage battery in [3], five non cooperative or cooperative game planning modes are proposed, and the optimal capacity allocation schemes of wind solar hybrid power system under each game planning mode are obtained. In [4], by analyzing the Stackelberg game relationship between DG planning and reactive capacitor planning, a bilevel programming model is proposed, in which the upper layer is the location and capacity determination of DG operators and the lower level is the location and sizing of reactive power capacitors and power purchase strategy of distribution network companies. Although all the above literatures have analyzed the game relationship among the agents, and established different types of game planning models from the perspectives of dynamic and static, cooperative and non cooperative, they do not consider the impact of source load side uncertainty on distribution network planning. In the incremental distribution network where distributed generation is widely connected, this method can not guarantee the accuracy of planning decision.

In the multi-agent game environment, the research on planning methods considering uncertainty is rare. Although the uncertainty of photovoltaic power generation is considered in the distribution network planning model based on Game Theory in [5], the treatment is very simple, and only a limited number of typical scenarios are considered. In [6], in the planning model based on game theory, both scenario method and scenario reduction method are adopted to achieve the accuracy of uncertain factors. The above literature describes the uncertainty in the system by scenario sampling, which on the one hand brings serious computational burden to the decision-making problem; on the other hand, the practice of using scenario reduction method to control the computational burden easily leads to the loss of small probability and high-risk scenarios in the process of reduction, which can not guarantee the feasibility of decision-making scheme in small probability and high-risk events. Different from scenario approach, robust optimization uses uncertain sets to describe uncertain parameters and takes the minimum cost under the worst scenario in the set as the decision objective, so as to minimize the interference of uncertainty on decision-making and ensure the feasibility of decision-making scheme. It is one of the most commonly used methods in uncertainty modeling field [7]. However, robust optimization deals with the influence of uncertainty factors on the whole planning

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decision-making from the overall point of view, while in the planning model of multi-agent game, people make decisions separately from the individual, and then seek the optimal scheme through the game between individuals. Therefore, in the planning problem of multi-agent game, the application of robust optimization method to deal with uncertainty is less.

To sum up, this paper proposes a distribution network planning method based on incremental game theory and multi-source game theory. Firstly, the planning decision-making model of DG investment operators, distribution network investment operators and power users is constructed, and then the robust optimization is used to deal with DG. In this paper, the uncertainty of output is introduced, and the virtual agent "nature", which represents the uncertainty, is introduced. On this basis, the above-mentioned subjects are taken as game participants, and the dynamic static joint game planning model is proposed. Finally, the iterative search algorithm and the mini-max method are used to solve the above model. Compared with the traditional methods, on the one hand, by accurately simulating the game behavior of the main players in the market, this method can ensure that each market entity continuously optimizes its own decision-making in the game process, so as to maximize its own revenue, and enhance the market vitality and the effectiveness of planning and decision-making; on the other hand, by introducing the virtual game player "nature", the game theory can be applied to the game theory In the model, the influence of uncertain factors on planning decision is fully considered, and the rationality of planning decision is improved by active optimization.

2 Market planning model

2.1 DG investment operators

DG investment operators are mainly responsible for the planning of distributed power supply in incremental distribution network planning, with the goal of maximizing their own income, and the decision variables are the location and capacity of distributed power. The distributed power supply considered in this paper is wind power generation.

The objective function of DG investment operator planning model mainly includes electricity sales revenue, investment cost and operation and maintenance cost. In addition, this paper also considers the government subsidies for renewable energy generation, and can be given by:

$$\max C^{DG}(x_s, N_s) = C_S^{DG} + C_c^{DG} - (C_I^{DG} + C_{OM}^{DG}) \quad (1)$$

The constraints of DG investment operator planning model mainly include the number of DG nodes to be selected, DG penetration constraints and DG output constraints.

The number of DG nodes to be selected is limited, and can be given by:

$$N_{s.\min} \le N_s \le N_{s.\max} \quad (2)$$

DG permeability constraint can be shown as:

$$\sum_{s=1}^{\Omega} x_s \cdot P_{sg}^{DG} \cdot N_s \le \delta \cdot P_{total} \quad (3)$$

DG output constraint can be given by:

$$P_{\min}^{DG} \le P_t^{DG} \le P_{\max}^{DG} \quad (4)$$

2.2 Distribution network investment operators

In the incremental distribution network planning, distribution network investment operators mainly plan the power grid, the goal is to maximize their own income, and the decision variable is the new line scheme.

The objective function of distribution network investment operator planning model mainly includes electricity sales revenue, new line investment cost, network loss cost, fault cost, power purchase cost of main network and power purchase cost of DG investment operators, and can be expressed as:

$$\max C^{DN}(y_k) = C_S^{DN} - (C_I^{DN} + C_L^{DN} + C_E^{DN}) \quad (5)$$

The constraints of distribution network investment operator planning model mainly include investment constraints of new lines, branch power flow constraints and security constraints.

Investment constraints of new lines can be given by:

$$\sum_{a=1}^{\Omega} y_{a.k} = 1 \quad (6)$$

Branch power flow constraints can be given by:

$$\begin{cases} P_{i.t} = U_{i.t} \cdot \sum_{j \in i} U_{j.t} \cdot (G_{ij} \cdot \cos\theta_{ij} + B_{i.t} \cdot \sin\theta_{ij}) \\ Q_{i.t} = U_{i.t} \cdot \sum_{j \in i} U_{j.t} \cdot (G_{ij} \cdot \sin\theta_{ij} - B_{i.t} \cdot \cos\theta_{ij}) \end{cases} \quad (7)$$

Security constraints can be given by:

$$\begin{cases} P_{ij.t} \le P_{ij.\max} \\ U_{i.\min} \le U_{i.t} \le U_{i.\max} \end{cases} \quad (8)$$

2.3 Power users

In the incremental distribution network planning, power users adjust their electricity consumption behavior by participating in the demand side response to reduce electricity expenses. This paper considers two demand side response modes: price based DSR based on TOU price and incentive DSR based on interruptible load. The users who participate in the price type DSR based on time of use price transfer the load during the peak period of electricity price, and transfer the load in the low price period; the users who participate in the incentive type DSR who participate in interruptible load can get

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corresponding compensation for interrupting and reducing the load in some periods by signing a contract with the power grid company.

The objective function of the power user planning model mainly includes the reduced electricity cost after participating in the demand side response and the interruptible load compensation cost, and can be given by:

$$\max C^{US}(P^{it}, P^{out}, P^{in}) = C_B^{US} + C_C^{US} \tag{9}$$

The transfer load power constraints can be given by:

$$\begin{cases} \lambda_{\min} P_t^{load} \le P_t^{out} \le \lambda_{\max} P_t^{load} \\ \mu_{\min} P_t^{load} \le P_t^{in} \le \mu_{\max} P_t^{load} \end{cases} \tag{10}$$

The interruptible load power constraints can be given by:

$$P_{\min}^{it} \le P_t^{it} \le P_{\max}^{it} \tag{11}$$

3 Multi-agent game behavior in power grid planning

The main market of this paper is DG investment operator, distribution network investor and power user. After the distributed power is connected, the uncertainty of its output will affect the operation safety of the distribution network, and increase the related costs, thus reducing the economic efficiency of the planning scheme of the distribution network investment operators. Therefore, the output of distributed power supply is considered as a special decision variable to represent its uncertainty, and "nature" is introduced as the corresponding virtual subject. The transfer relationship of each subject in planning decision-making is shown in Figure 1. DG investment operators will select and fix the location and capacity of DG under the current grid structure, and transfer the location and capacity of DG to the distribution network investment operators and "nature". The power users take the information of time-sharing price and the information of interruptible load incentive to formulate active response measures, namely, determine the power of transfer load and interruptible load, and feed back to the distribution network investment operator in the form of equivalent load. "Nature" interferes with the planning of distribution network investment operators when they know the DG distribution points and combine with the current grid structure, and calculate the DG output and transmit it to the distribution network investment operators. The distribution network investment operators accept the information from other entities, and decide to build new lines and form a new network structure. According to the transfer relationship among the main bodies, the power users only obtain the time-sharing price and interruptible incentive information from the distribution network investment operators, which is not directly affected by their decision-making, but transfer their decision results to the distribution network investment operators for the planning and decision-making of the network. Therefore, when analyzing the game behavior of each subject, the power users are not regarded as games participants.

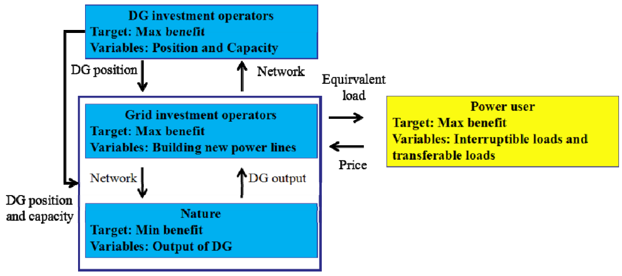

Figure 1. Transfer relationship chart between each subject.
Static game analysis

3.1 Static game analysis

Due to the need to complete the planning and construction of incremental distribution network under the premise of independent decision-making, DG investment operators and distribution network investment operators master each other's strategic information in the planning process, and both make decisions at the same time, and there is no sequence of actions A complete information static game pattern is formed between investment operators and distribution network investment operators.

In a game round, after receiving time of use price information and interruptible load incentive information, power users determine the power of transfer load and interruptible load, and feed back to distribution network investment operators in the form of equivalent load. According to the decision of the last round of DG investment operators on the location and capacity of DG and the load information fed back by power users, the distribution network investment operators adjust the new line scheme to maximize the total benefit of the distribution network. At the same time, according to the decision of the last round of distribution network investment operators on the new lines, the DG investment operators adjust the location and sizing scheme of DG to make DG The investment and operation benefit is the most. After updating the network topology and DG location and capacity, the next game round is entered.

3.2 Dynamic game analysis

The above planning process is deterministic planning. However, for the distribution network planning problem with distributed generation, people always want to design the optimal strategy to minimize the possible cost loss or operation risk, and to restrain the adverse impact caused by uncertainty to the greatest extent. This process is related to robust optimization The thoughts of the two are consistent. Therefore, this paper adopts robust optimization method to deal with the uncertainty of DG output, and describes the fluctuation range of output through the uncertain interval. Since DG is considered as wind power generation in this paper, when wind speed is

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a certain quantity, the output of wind turbine will only depend on the installed capacity of wind power.

In the above robust optimization problems, DG The uncertainty of output will reduce the profit of distribution network, and the goal of network planning is to maximize the profit of distribution network, that is, the objective function of "nature" is the opposite value of the objective function of distribution network investment operators. From the perspective of game theory, two decision makers "nature" and distribution network investment operators form a zero sum game relationship, so robust optimization can be achieved The problem is transformed into a game between "nature" and distribution network investment operators. In the face of game players such as "nature", the best way to deal with it is to observe the worst interference, and then construct countermeasures, thus forming a dynamic game process in which the actions of the two have a sequence in the game round. The game flow is shown in Figure 2.

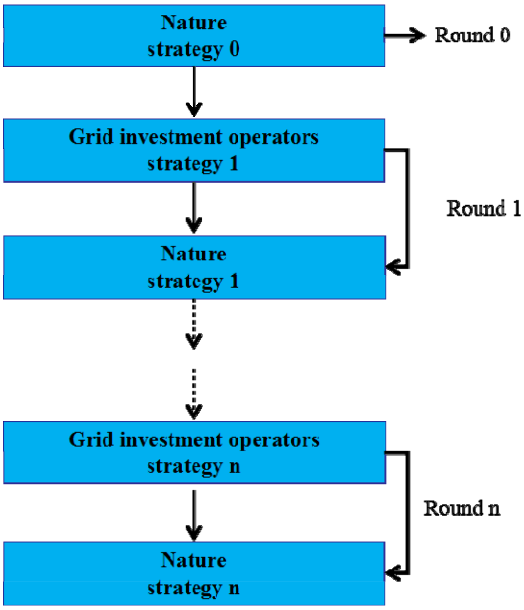

Figure 2. Dynamic game flow chart.

4 Conclusions

In this paper, the idea of game theory and robust optimization is integrated into the incremental distribution network planning, and a source load collaborative planning method for incremental distribution network considering uncertainty and multi-agent game is proposed. In this paper, by accurately simulating the dynamic static joint game behavior between market participants and DG output uncertainty, each market entity can continuously optimize its own decision-making in the game process, so as to maximize its own revenue and improve the market vitality and the effectiveness of planning and decision-making. At the same time, by introducing the virtual game player "nature", the uncertainty of DG output is fully considered in the planning model considering multi-agent game. By actively changing the network topology structure, the robustness of DG output is stronger and the planning result is more reasonable. Compared with scenario method, robust optimization is used to deal with uncertainty, which can effectively improve the efficiency of solving the model.

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