Research on declaration strategy of virtual power plant spot market considering transaction price risk

Jie He\textsuperscript{a*}, Xi Luo\textsuperscript{b*}, Wen Zhao\textsuperscript{c}

\textsuperscript{a} Zhejiang Electric Power Trading Center Co. LTD, Hangzhou 310000, China
\textsuperscript{b} 86895687@qq.com, \textsuperscript{c} 1198356934@qq.com, \textsuperscript{a} 158133580@qq.com

Abstract—In order to control the risk of power spot market price fluctuation on the operation benefit of virtual power plant, the transaction risk of virtual power plant operator is studied, and the virtual power plant declaration strategy considering spot transaction risk is proposed. The fluctuation of spot market price may cause the profit change or even loss of virtual power plant. According to the expectation of market price fluctuation, the expected risk constraint of virtual power plant based on conditional value at risk is established to ensure that the transaction risk of virtual power plant declaration strategy is within its tolerable range. On this basis, a virtual power plant spot market declaration strategy model considering transaction price risk is proposed. The model optimizes the maximum expected return and considers the constraints including expected risk constraints. Finally, an example is constructed based on the actual data of a virtual power plant to verify the effectiveness of the proposed method.

1. Introduction

Virtual power plant is a kind of special user cluster. Relying on advanced information communication and operation control technology, it can realize the flexible invocation of internal adjustable power supply, so as to interact with the demand of large power grid and promote the absorption of new energy [1-2]. In recent years, with the acceleration of the construction of spot market, the supporting business model of virtual power plant operation is increasingly mature, which speeds up the research and application of virtual power plant. Therefore, the problem of declaration strategy design of virtual power plant in spot market transaction arises.

Literature [3-4] studies the optimization scheduling problem of virtual power plants. Based on the price forecast data of the spot market, an optimization model is constructed with the goal of maximizing the expected income of virtual power plants. The optimization results can be used as a reference for the application of virtual power plants. On the basis of literature [5-6], demand-side response and operation characteristics of energy storage devices are further considered to build a more refined optimization scheduling model. The above methods can solve the problem of optimal dispatching of virtual power plant under given clearance results, and can also be used as the basis for the formulation of its declaration strategy. In order to make declaration strategy more directly, literature [7-8] constructed virtual power plant declaration strategy based on game model, and provided decision-making reference for virtual power plant operators through game analysis among different market entities of large power grid. Literature [9-10] builds a declaration strategy decision-making model with the goal of maximizing its own expected returns, and formulates declaration strategies considering the impact of expected clearing price fluctuations on expected returns.

It can be seen that the current virtual power plant spot market transaction declaration strategy design is mainly based on its expected benefits in the spot market transaction. The existing research on
the operating costs and expected benefits of virtual power plants under different operating modes has carried out a relatively comprehensive study. However, the risk of spot market price fluctuation is not considered comprehensively. In fact, as a key reference for declaration decision, the volatility of spot market transaction price has a significant impact on declaration strategy. During the formulation of the declaration strategy, the operators of virtual power plants should not only consider the expected benefits that the declaration strategy may produce, but also do a good job in the risk prevention and control of the price fluctuation of the spot market. Otherwise, the deviation between the actual income and the expected income may be large, bringing great losses to the virtual power plants.

Therefore, this paper will study the virtual power plant spot market declaration strategy design considering price risk. Firstly, the basic concept of conditional value risk is introduced and the transaction risk constraint based on conditional value risk is proposed. Secondly, with the goal of maximizing expected return, the model of reporting strategy considering transaction risk constraint and operation characteristic constraint is constructed. Finally, an example is constructed to verify the effectiveness of the proposed method.

2. Transaction risk constraints based on conditional value at risk

In the design of virtual power plant declaration strategy considering the volatility risk of spot market transaction price studied in this paper, the spot market transaction price volatility can be evaluated by multi-scenario prediction model, which can be expressed as:

\[
p(t) = \begin{pmatrix}
p_1(t) & \rho_1 \\
p_2(t) & \rho_2 \\
\vdots & \vdots \\
p_N(t) & \rho_N
\end{pmatrix}
\]  

(1)

Where \( p(t) \) is the fluctuation vector of the trading price of the spot market. \( p_1(t), p_2(t), \ldots, p_N(t) \) are the price time series under scenario 1, scenario 2 to scenario N respectively. \( \rho_1, \rho_2, \ldots, \rho_N \) are the probability of each scene, which satisfies:

\[
\sum_{k=1}^{N} \rho_k = 1
\]  

(2)

where \( N \) is the number of forecast scenarios of spot market transaction price.

Based on the above multi-scenario prediction results of spot market transaction price, conditional value at risk of market transaction risk conditions can be expressed as:

\[
CVaR = Var + \frac{1}{1-K} \sum_{k=1}^{N} \rho_k [Ear^{set} - Ear_k - Var]^-
\]  

(3)

where \( Ear^{set} \) and \( Ear_k \) respectively represent the expected demand for virtual power plant revenue and the expected benefit under the scenario, and is a positive function, which satisfies:

\[
[Ear^{set} - Ear_k - Var]^+ = \begin{cases}
Ear^{set} - Ear_k - Var & Ear^{set} - Ear_k - Var > 0 \\
0 & Ear^{set} - Ear_k - Var \leq 0
\end{cases}
\]  

(4)

In order to meet the requirements of market transaction risk prevention and control, it can be expressed in the form of constraint terms with reference to the conditional var of the virtual power plant in the spot market transaction price fluctuation:

\[
Var + \frac{1}{1-K} \sum_{k=1}^{N} \rho_k [Ear^{set} - Ear_k - Var]^+ \leq Var^{set}
\]  

(5)

where \( Var^{set} \) is the maximum loss risk accepted by the virtual power plant.
3. Virtual power plant declaration strategy considering transaction price risk

At present, the research of virtual power plant is deepening, and there have been studies on the application of adjustable power sources such as carbon capture and electricity to gas in virtual power plant. Considering the main content of this paper, the model design focuses on virtual power plants with three types of adjustable power including new energy, controllable load and energy storage device. Other virtual power plants can further improve the corresponding objective function and constraint conditions on this basis.

3.1. Optimization Objective

The virtual power plant declaration strategy design aims at minimizing the expected cost of market transactions, which can be expressed as:

$$\min \text{Ear}(P_{i}^{VPP}) = \text{Ea}(P_{i}^{VPP}) + \text{Co}(P_{i}^{NE}, P_{i}^{CL}, P_{i}^{BS})$$

(6)

where $\min$ represents the minimization planning problem. $\text{Ear}(P_{i}^{VPP})$, $\text{Ea}(P_{i}^{VPP})$ and $\text{Co}(P_{i}^{NE}, P_{i}^{CL}, P_{i}^{BS})$ are the expected cost of virtual power plant, expected power purchase cost and expected operating cost respectively.

Expected power purchase cost is the total power purchase cost calculated based on multi-scenario prediction of spot market transaction price and declared exchange power of virtual power plant, which can be expressed as:

$$\text{Ea}(P_{i}^{VPP}) = \sum_{k=1}^{N} \sum_{t=1}^{T} P_{i}^{VPP} p_{k}(t) \Delta T$$

(7)

where $P_{i}^{VPP}$ is the exchange power of the virtual power plant during the period of time. $p_{k}(t)$ is the predicted value of the spot market trading price during the period $t$ of the scene $k$. $NT$ and $\Delta T$ are the time interval and time length respectively.

The expected operating cost is the operating cost of various adjustable power supplies, which can be expressed as a quadratic function as follows:

$$\text{Co}^{NE} = a^{NE} P_{i}^{NE2} + b^{NE} P_{i}^{NE} + c^{NE}$$

(8)

$$\text{Co}^{CL} = a^{CL} P_{i}^{CL2} + b^{CL} P_{i}^{CL} + c^{CL}$$

(9)

$$\text{Co}^{BS} = a^{BS} P_{i}^{BS2} + b^{BS} P_{i}^{BS} + c^{BS}$$

(10)

where $\text{Co}^{NE}$, $\text{Co}^{CL}$ and $\text{Co}^{BS}$ respectively are the operating costs of three types of adjustable power supplies: new energy, controllable load and energy storage device. $a^{NE}$, $b^{NE}$ and $c^{NE}$ are the quadratic term coefficient, the primary term coefficient and the constant term coefficient of the quadratic function of the operating cost of new energy. $a^{CL}$, $b^{CL}$ and $c^{CL}$ are the quadratic term coefficient, primary term coefficient and constant term coefficient of the quadratic function of controllable load operating cost respectively. $a^{BS}$, $b^{BS}$ and $c^{BS}$ are the quadratic term coefficient, primary term coefficient and constant term coefficient of quadratic function of operating cost of energy storage device respectively. $P_{i}^{NE}$, $P_{i}^{CL}$ and $P_{i}^{BS}$ respectively refers to the power generation output of new energy, controllable load, energy storage device, call load or exchange power.

The sum of the operating costs of the above three types of adjustable power supplies is the expected operating costs of the virtual power plant, which can be expressed as:

$$\text{Co}(P_{i}^{NE}, P_{i}^{CL}, P_{i}^{BS}) = \text{Co}^{NE} + \text{Co}^{CL} + \text{Co}^{BS}$$

(11)
3.2. Constraints

The constraint conditions to be considered include five categories, which are power balance constraint, new energy operation characteristic constraint, controllable load operation characteristic constraint, energy storage device operation characteristic constraint and transaction risk constraint.

(1) Power balance constraint

Power balance constraint requires that the switching power of virtual power plant and large power grid must match the operation plan of its adjustable power supply, which can be expressed as:

\[ P_{t}^{VPP} = P_{t}^{VPP,L} - P_{t}^{NE} - P_{t}^{CL} - P_{t}^{BS} \]  

(12)

where \( P_{t}^{VPP,L} \) represents the power load of the virtual power plant during the period without considering the influence of controllable power supply.

(2) Constraints on the operation characteristics of new energy

Constraints on the operation characteristics of new energy require that the power generation output plan of new energy should not exceed its predicted power generation output, and the deviation is wind and light abandoning power, which can be expressed as:

\[ P_{t}^{NE} = P_{t}^{NE,F} - P_{t}^{NE,A} \]  

(13)

where \( P_{t}^{NE,F} \) and \( P_{t}^{NE,A} \) are respectively predicted output and wind and light abandoning power during the new energy period.

(3) Constraints on controllable load operation characteristics

The constraints of controllable load operation characteristics are related to the response requirements of controllable load. In reference to the response requirements of controllable load in reference [], the constraints of controllable load operation characteristics require that the response quantity of controllable load does not exceed its response limit and can only respond in the specified response period, which can be expressed as:

\[ P_{t}^{CL} \leq P_{t}^{CL,max} \]  

(14)

\[ P_{t}^{CL} = 0 \quad t \notin \text{CLR} \]  

(15)

where \( P_{t}^{CL,max} \) is the maximum response load limit of controllable load, and \( t \) is the time set of allowable response period.

(4) Constraints on operation characteristics of energy storage devices

The operating characteristic constraints of energy storage devices include switching power constraints, discharging capacity constraints, charging capacity constraints, charge-discharge state constraints, storage capacity constraints, and constant storage capacity constraints, which can be expressed as:

\[ P_{t}^{BS} = P_{t}^{BS,D} - P_{t}^{BS,C} \]  

(16)

\[ 0 \leq P_{t}^{BS,D} \leq \mu_{t}^{BS,D} P_{s}^{BS,D,max} \]  

(17)

\[ 0 \leq P_{t}^{BS,C} \leq \mu_{t}^{BS,C} P_{s}^{BS,C,max} \]  

(18)

\[ \mu_{t}^{BS,D} + \mu_{t}^{BS,C} = 1 \]  

(19)

\[ E_{t}^{BS,min} \leq E_{t}^{BS} + \sum_{\tau=1}^{t} (\eta_{t}^{BS} P_{t}^{BS,C} - P_{\tau}^{BS,D}) \Delta T \leq E_{t}^{BS,max} \]  

(20)

\[ \sum_{t=1}^{NT} (\eta_{t}^{BS} P_{t}^{BS,C} - P_{t}^{BS,D}) \Delta T = 0 \]  

(21)

where \( P_{t}^{BS,D} \) and \( P_{t}^{BS,C} \) are respectively the discharging power and charging power of the energy storage device during the period of time. \( P_{s}^{BS,D,max} \) and \( P_{s}^{BS,C,max} \) are respectively the maximum
discharging power and maximum charging power of the energy storage device. $\mu_t^{BS,D}$ and $\mu_t^{BS,C}$ are respectively the discharge state variables and charging state variables of the energy storage device during the period of time $t$. $E_0^{BS}$ is the initial electric energy storage device. $E_{BS,\min}^{BS}$ and $E_{BS,\max}^{BS}$ are respectively the maximum and minimum electric energy storage device, $\eta^{BS}$ is the loss coefficient converted to the charging side.

(5) Transaction risk constraints

Transaction risk constraint requires that the conditional value at risk should not exceed its limit value under the transaction price fluctuation of the spot market, which has been expressed in formula (5) of this paper.

4. Case study

In order to verify the effectiveness of the proposed method, an example is constructed to verify the effectiveness of the proposed method based on the actual data of a virtual power plant. The operation data of the virtual power plant are as follows:

(1) The installed capacity of new energy is 150MW, of which the installed capacity of wind power is 86MW and that of photovoltaic is 64MW. The power generation output is mainly determined by the predicted power generation;

(2) The maximum response load of controllable load is 20MW, which can be in the morning peak at 10:00-13:00 and evening peak at 17:00-21:00;

(3) The initial storage capacity of the energy storage device is 10MWh, the maximum storage capacity is 100MWh, and the maximum exchange power is 25MW.

The fluctuation prediction of spot market price is shown in Figure 1. The probability of occurrence of spot market price in scenario 1 is 30%, scenario 2 is 30%, and scenario 3 is 40%.

On this basis, the calculation example will further compare the operating benefits of the following two methods:

Method 1: Based on the operation benefit of the method proposed in this paper;

The second method does not consider the operating benefit of the spot market transaction price fluctuation risk.

As shown in Figure 2, from the perspective of expected return, the expected return of method 2 is higher than that of method 1, and its price fluctuation risk is also significantly higher than that of method 1. The reason for the above results is that although the second method takes into account the change of expected earnings of virtual power plants in the process of spot market price change, the change of expected earnings of virtual power plants in the process of spot market price change may exceed the tolerance range due to the lack of price fluctuation risk constraint. The method proposed in this paper can effectively avoid the above problems.
5. Conclusion
In order to make the declaration strategy scientifically and prevent the transaction risk under the fluctuation of the trading price in the spot market, this paper puts forward the virtual power plant declaration strategy considering the transaction price risk. This method can consider the transaction risk changes under the transaction price fluctuation, ensure the transaction risk of the declaration strategy is controllable, and can be used as the basis for virtual power plant operators to formulate the declaration strategy.

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