Research on Power Purchasing Strategy of Power Grid Enterprise Agent Considering the Responsibility of Renewable Energy Consumption

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Abstract: With the rise of the Power Grid Company's power purchasing agency business and the continuous improvement of the renewable energy absorption mechanism, it is of great significance to study the optimal power purchase strategy with the consideration of the cost minimization and the risk reduction of renewable energy consumption. This paper synthetically considers the factors of electricity price fluctuation, uses CVaR method to quantify the risk in the process of electricity purchase, considers the distribution of electricity price under different excess consumption, and establishes the cost-risk model of electricity purchase, to seek the lowest cost, risk controllable power purchase strategy. The example shows that the higher the risk-bearing capacity of the agent, the larger the proportion of the agent in the spot market. And power grid companies can according to the trust of historical data and the future excess consumption of supply and demand, choose their own purchasing strategy.

Keywords: Power purchasing agent; Power purchase decisions; CVaR method

1. Introduction

In order to promote the optimal allocation of power resources nationwide, the National Development and Reform Commission (NDRC) promulgated the Notice on Establishing and Improving the Guarantee Mechanism for Renewable Energy Power Consumption in 2019, proposing that China will establish and improve the Guarantee Mechanism for Renewable Energy Power Consumption. At present, the weight mechanism of renewable energy consumption refers to the proportion of renewable energy consumption that should be achieved according to the administrative region, including the weight of responsibility for total renewable energy consumption and the weight of responsibility for non-hydro renewable energy consumption. As a new member of the electricity market and the focus of China's electricity market reform, actively undertaking the obligation of renewable energy power consumption is an important content that grid companies should consider when purchasing electricity as an agent.

Existing articles on the study of power purchase strategy, article [1] discusses the optimization strategy of power purchase in the monthly market under the background of medium and long-term transactions. Article [2] analyzes and summarizes the power sale decision-making and risk management in the process of power sale. Article [3] optimizes the power purchase model from

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the perspective of large users. The risk factors in the process of purchasing electricity are generally measured by the methods of value at risk, conditional value at risk and information entropy [4-5].On this basis, this paper comprehensively considers the transactions in the medium and long-term contract market and the spot market, uses the conditional value at risk model as a risk measurement tool, and considers the excess consumption transaction at the same time, constructs the power purchasing decision-making model for the grid company to participate in the electricity contract market, the spot market and the excess consumption market, and studies the optimal strategy of agent purchasing.

2. Conditional Value at risk method

CVaR method is the theory of conditional value-at-risk, which is improved on the basis of var method [6]. As a risk measurement tool, CVaR can measure that the loss caused by investment decision exceeds the average value of Var under a certain confidence level in the investment process. Compared with the traditional Var method, it can measure the risk of investment strategy more comprehensively [7] and reflect the potential risk in investment decision.

Let f(x, y) be the loss function, x be the n-dimensional decision vector of the investment strategy, where $x \in X$ (X is the feasible set of decision variables), and y is a multidimensional random variable in the market. According to the definition of VaR, the mathematical formula of VaR is expressed as:

$$P[f(x,y) > G_{VaR}] = 1 - \beta \quad (1)$$

β denotes the confidence level, and $P[f(x,y) > G_{VaR}]$ is the probability that the investment loss is greater than the value of VaR.G_{VaR} is value at risk at confidence level β.

According to the definition of CVaR, the mathematical formula of CVaR can be expressed as:

$$G_{CVaR} = E[f(x,y)|f(x,y) \geq G_{VaR}]$$
$$= \frac{1}{1-\beta}\int_{f(x,y)\geq G_{VaR}} f(x,y)p(y)dy \quad (2)$$

$E[f(x,y)|f(x,y) \geq G_{VaR}]$ is the expectation of $f(x,y)$ in the case of $f(x,y) \geq G_{VaR}$, and $p(y)$ is the probability density function of random y. Since it is difficult to obtain$p(y)$ expression in practical application, it is usually estimated by random sampling. Assuming that N groups of sample data are sampled by sampling method, the formula (2) can be approximately expressed as follows:

$$G_{CVaR} = G_{VaR} + \frac{1}{(1-\beta)N}\sum_{i=1}^{N}[f(x,y_i) - G_{VaR}]^+ \quad (3)$$

$$[C(\omega,p_i) - G_{VaR}]^+ = max[C(\omega,p_i) - G_{VaR}, 0\}. \quad (4)$$

The CVaR index is used as a tool to measure the risk of different power purchasing combinations when the grid company purchases power as an agent, and the power purchasing cost under extreme conditions is considered to the maximum extent. The higher the value, the higher the cost of purchasing electricity under extreme conditions, and the greater the risk of purchasing electricity borne by the main body of the sale-side market.

3. Power purchase cost model based on CVaR method

The consumption guarantee mechanism of renewable energy requires the consumers to complete the consumption of non-water renewable energy and the total amount of renewable energy, and the paths for grid companies to purchase electricity include the electricity contract market, the electricity spot market and the excess consumption market. In the medium and long-term contract market, power grid companies can define the type of electricity purchased by signing contracts with power generation enterprises, so the medium and long-term contract market can be divided into non-water renewable energy contracts, hydropower contracts and traditional energy power contracts. However, in the spot market, it is not clear whether the electricity purchased by the grid company is renewable energy when purchasing electricity on behalf of the grid company, and in the current spot rules, there is no relevant implementation rules to give the allocation method of renewable energy consumption in the spot electricity market. Therefore, this paper assumes that the renewable energy consumption obtained by market participants in the spot market is allocated according to the principle of equal proportion.

Taking a power grid company as an example, suppose its power purchase proportion matrix in each market is ω^{T}, and the corresponding price matrix is p^{T}:

$$\omega^{T} = (\omega_r, \omega_l, \omega_h, \omega_s, \omega_e) \quad (5)$$

$$p^{T} = (p_r, p_l, p_h, p_s, p_e) \quad (6)$$

Among them, $\omega_r, \omega_l, \omega_h, \omega_s, \omega_e$ represents the transaction proportion of grid companies in non-water renewable energy contract market, traditional energy contract market, hydropower contract market, spot market and excess consumption market respectively, and p_r, p_l, p_h, p_s, p_e sub-table represents the electricity price of each market. Considering that most electricity price forecasting models use normal distribution to represent the uncertainty of electricity price information, each market in this paper also uses normal distribution model to simulate the random fluctuation of electricity prices in different markets.

The unit cost of power purchased by the grid company can be expressed as:

$$C(\omega, p) = \omega^{T} p$$
$$= \omega_r p_r + \omega_l p_l + \omega_h p_h + \omega_s p_s + \omega_e p_e \quad (7)$$

Taking the cost function of unit power purchase as the loss function, combining with the historical samples of power grid company's agent power purchase, according to the distribution characteristics of electricity prices collected in different markets in the past, random sampling is carried out to generate N groups of electricity price combinations in different markets. Then the risk of power purchase conditions can be expressed as:

$$G_{CVaR} = G_{VaR} + \frac{1}{(1-\beta)N} \sum_{i=1}^{N} [C(\omega, p_i) - G_{VaR}]^{+} \quad (8)$$

Since the electricity price in each electricity market follows the normal distribution, the minimum unit electricity purchase cost of the electricity purchaser is taken as the objective function:

$$\min\{E[C(\omega, p)]\} \quad (9)$$

The constraints are as follows:

$$\begin{cases} G_{CVaR} \leq \varphi \\ 0 \leq \omega_r \leq 1 \\ 0 \leq \omega_l \leq 1 \\ 0 \leq \omega_h \leq 1 \\ 0 \leq \omega_s \leq 1 \\ \omega_r + \omega_l + \omega_h + \omega_s = 1 \\ \omega_r + \gamma\omega_s + \omega_e \geq R_1 \\ \omega_r + (\gamma + \delta)\omega_s + \omega_h + \omega_e \geq R_2 \end{cases} \quad (10)$$

φ represents the maximum value of power purchase loss that the grid company can accept when purchasing power as an agent, and the higher φ is, the greater the ability of the grid company to bear risks when purchasing power as an agent. γ and δ represent the share of non-hydro renewable energy and hydropower transactions in spot transactions, respectively.

R_1 is the weight index of non-water consumption on the power selling side, and R_2 is the total consumption weight of all renewable energy.

4. Example analysis

Taking the price of electricity in a certain area as an example, suppose that the non-water renewable resources responsibility weight index of the sale-side market main body is 18% , and the total absorption weight is 20% .Suppose that the share of hydropower and non-water renewable energy consumption in the spot market are $\gamma = 0.1$ and $\delta = 0.05$.On the basis of this data, use Monte Carlo random sampling to generate 50 groups of electricity price scenarios in different markets, use particle swarm optimization, set the number of particles to be 100, and the maximum number of iterations to be 200 for simulation optimization, and finally obtain the optimal electricity purchase strategy in different scenarios, as shown in Table 2-5.

Table 1 The price of electricity for each trade varieties

Trade varieties	Average price of electricity	Standard deviation of electricity price
Non-water renewable energy contract transactions	560	5
Other traditional energy contract transactions	450	5
Water and electricity contract transactions	480	5
Spot Market	420	60
Over-absorption transactions (Supply equals demand)	148	30
Over-absorption transactions (Supply exceeds demand)	130	30
Over-absorption transactions (Demand exceeds supply)	164	30

Table 2 β=0.9, Power purchase strategy when supply equals demand

cvar (yuan/MW·h)	ω_r	ω_l	ω_h	ω_s	ω_e	E (yuan/MW·h)
470	0.13	0.69	0.02	0.16	0.03	464.54
485	0.11	0.66	0.01	0.22	0.05	463.2
500	0.09	0.63	0.02	0.26	0.07	463.06
520	0.08	0.59	0.02	0.31	0.07	460.46

Table 3 β=0.95, Power purchase strategy when supply equals demand

cvar (yuan/MW·h)	ω_r	ω_l	ω_h	ω_s	ω_e	E (yuan/MW·h)
470	0.14	0.72	0.02	0.12	0.03	466.84
485	0.12	0.69	0.01	0.18	0.05	465.5
500	0.11	0.65	0.01	0.23	0.05	462.9
520	0.10	0.59	0.02	0.29	0.06	461.78

Comparing Table 2 and Table 3, it can be seen that the increase of confidence level means that the probability of the potential maximum power purchase cost becomes smaller, the higher the risk-averse degree is, the more conservative the purchasing strategy is. That is to say, with the increase of confidence level, the proportion of power purchase in medium-and long-term contract market will increase, and the proportion of power purchase in spot market will decrease.

Table 4 β=0.95, Power purchase strategy when demand exceeds supply

cvar (yuan/MW·h)	ω_r	ω_l	ω_h	ω_s	ω_e	E (yuan/MW·h)
470	0.13	0.71	0.04	0.12	0.04	468.46
485	0.16	0.66	0.04	0.14	0.01	466.24
500	0.16	0.58	0.03	0.23	0	461.6
520	0.16	0.55	0.03	0.265	0	460

Table 5 β=0.95, Power purchase strategy when supply exceeds demand

cvar (yuan/MW·h)	ω_r	ω_l	ω_h	ω_s	ω_e	E (yuan/MW·h)
470	0.035	0.78	0.015	0.17	0.13	466.1
485	0.03	0.75	0.01	0.21	0.13	464.2
500	0.02	0.73	0	0.25	0.14	462.9
520	0.01	0.69	0	0.3	0.14	460.3

From the comparison of Tables 3, 4 and 5, it can be seen that from the perspective of the supply and demand situation of the excess consumption market, when supply exceeds demand, due to the low average price of the excess consumption market, the willingness to consume new energy in the medium and long-term contract market is low, and the power purchasers tend to purchase excess consumption instead of actual consumption, thus completing the responsibility weight index.In the market where supply and demand are balanced and supply is less than demand, the risk tolerance of market participants has little impact on the consumption of non-water renewable energy. The proportion of electricity purchased by the trading variety remains relatively stable, and the market participants on the sales side will fulfill their consumption responsibilities mainly by purchasing non-water renewable energy electricity.

5. Conclusion

In this paper, the conditional value at risk model is used as a risk measurement tool, and considering the transactions in the medium and long-term contract market and the spot market, the power purchasing decision models for grid companies to participate in the electricity contract market, the spot market and the excess consumption market are constructed. The model is used to carry out an example analysis, and the optimal power purchase proportion allocation scheme of the market participants on the selling side is given under different market supply and demand relations of excess consumption and the size of risk loss, which provides a method for the market participants on the selling side to participate in the electricity market competition, and helps the power purchasing enterprises to choose power purchasing strategies and reduce power purchasing costs. Through the analysis, the following conclusions are drawn:

(1) Power grid companies should assess their own risk tolerance when purchasing electricity as an agent. The greater the risk they can bear, the more inclined they are to purchase electricity in the spot market and other markets with large risk fluctuations but low price expectations, and the lower the expected cost of purchasing electricity.

(2) The supply and demand situation of the excess consumption market has a very important impact on the construction decision when the grid company acts as an agent to purchase electricity. According to the relationship between supply and demand in the excess consumption market, the power purchasers need to adjust the distribution ratio of power purchase in the excess consumption market and the renewable energy contract market, so as to reduce the unit cost of power purchase while achieving the target of renewable energy consumption.

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