Purchase and Sale Strategies for Power Retailers Considering Risks

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Abstract. Renewable energy has become one of the sources of purchase for power retailers in the power market, due to its low cost and environmental protection. It is important to analyze the business risks brought by various uncertainties for the power retailers during the process of purchase and sale of renewable energy. Aiming at the diversity of market combinations and a series of uncertainties with the market, a multi-objective optimization model of purchase and sale for power retailers considering risks was established in this paper by coordinating the profit and risk of purchase and sale based on the theory of risk element transmission. The example showed that the strategy proposed by this paper can provide decision-making reference for power retailers and promote the consumption of renewable energy.

Introduction

Renewable energy is being accessed on a large scale due to its low cost, clean and eco-friendly features. The combination of renewable energy market and traditional power market can bring more profits to power retailers [1,2]. However, Huge risks are brought to the healthy and efficient operation of power retailers through uncertainties such as renewable energy output, load forecasting, and price in power market, etc. Therefore, it is important for power retailers to conduct risk analysis on the process of purchase and sale, then make decisions between risk and profit. Some studies have considered risks of purchase and sale but ignored renewable energy market [3,4], while others have conducted research on renewable energy market but have not quantified its risks [5,6]. For the power retailers who include renewable energy purchases, this paper considered the problem of the purchase and sale as a combination of investments. The target of the power retailers is to pursue the maximum profit at a lower risk by rationally distributing the power purchase between the various levels of the market and establishing a reasonable price for power sales, while meeting the load demand. A multi-objective optimization model of purchase and sale for power retailers with renewable energy purchase considering risks based on the theory of risk element transmission was established in this paper to formulate the purchase and sale strategy. Finally, an example is provided to analyze the purchase and sale strategy.

Purchase and Sale Strategy for Power Retailers

Basic Assumption

Renewable energy markets, traditional power markets, standby markets, and captive power plants were assumed to be power access to the power retailers in this paper. Power purchase was allocated to the medium and long-term market and the spot market from a time scale perspective, in order to fully consider the risks generated by the power retailers in the pursuit of economic benefits and make better trade-offs between profits and risks. Contracted power in the renewable energy market as well as in the traditional power market was included in the medium and long-term market. The on-grid power in
renewable energy market, the retail power in traditional power market, the auxiliary power of reserve market and the backup power of the captive power plant were included in the spot market.

In the medium and long-term time scale, the trading process was relatively stable and the risk was low because the transaction price and power were settled according to the contracts. \( P_n^r \) indicates the contract price of renewable energy market, \( P_m^r \) represents the contract price of traditional power market, \( Q_n^r(t) \) and \( Q_m^r(t) \) indicate their contracted power at a certain time.

On the spot time scale, more profits can be sought because of the flexible power price, but it will also generate more risks. The sources of the risks of purchase and sale at this time scale were mainly composed of the fluctuation of power price in the market, the uncertainty of renewable energy output and load forecasting. In a certain period of time, \( P_n^r(t) \), \( \mu_n(t) \) and \( \sigma_n^2(t) \) represent the price of renewable energy market, its average value and variance of price respectively; \( P_m^r(t) \), \( \mu_m(t) \) and \( \sigma_m^2(t) \) represent the price in traditional power market, its average value and variance of price respectively; \( P_r(t) \) and \( P_o(t) \) indicate the price of the reserve market and the captive power plant respectively. \( Q_n^r(t) \), \( Q_m^r(t) \), \( Q_r(t) \) and \( Q_o(t) \) indicate the purchase of power corresponding to each market. \( D(t) \), \( \mu_d(t) \) and \( \sigma_d^2(t) \) indicate the load of the power supply area, the average value of the load forecast and its variance; \( Q_s(t) \), \( \mu_s(t) \) and \( \sigma_s^2(t) \) indicate the output of the renewable energy, the average value of the output and its variance; \( P_s(t) \) is the price of power sale.

**Optimization Model of Purchase and Sale for Power Retailers**

The economic benefits of the purchase and sale for power retailers is shown in Eq. 1, where \( F \) represents the total profit of the purchase and sale for power retailers throughout the day, \( \Delta T \) represents the time interval and \( T \) represents the trading period. Assuming that the prices of the various levels of the market are independent of each other, then the mean value of the economic benefits of the purchase and sale for power retailers expressed by \( \bar{F} \) is shown in Eq. 2.

\[
F = \Delta T \sum_{i=1}^{T} \left\{ D(t) P_r(t) - \left[ P_n^r(t) Q_n^r(t) + P_m^r(t) Q_m^r(t) + P_o(t) Q_o(t) + P_r(t) Q_r(t) \right] \right\}
\]

\[
\bar{F} = E(F) = \Delta T \sum_{i=1}^{T} \left\{ \mu_r(t) P_r(t) - \left[ P_n^r(t) Q_n^r(t) + P_m^r(t) Q_m^r(t) + \mu_o(t) Q_o(t) \right] \right\}
\]

According to the theory of risk element transmission, the risks of purchase and sale caused by uncertainty of the price in renewable energy market, load forecasting and the price in traditional power market, denoted by \( R_s(t) \), \( R_d(t) \) and \( R_n(t) \) respectively, are shown in Eq. 3 to Eq. 5, where \( c_1(t) \) indicates the risk element transmission coefficient of renewable energy market to income; \( c_2(t) \) represents the risk element transmission coefficient of load forecasting to revenue; \( c_3(t) \) represents the risk element transmission coefficient of traditional power market to revenue. Their specific formula is shown in Eq. 6, Eq. 7 and Eq. 8, where \( \omega_1 \) indicates the weight of the renewable energy market price risk elements on the power purchase, \( \omega_2 \) indicates the weight of the load risk element on the selling price, \( \omega_3 \) represents the weight of the traditional power market price risk element on the power purchase. The overall risk of purchase and sale for power retailers over the full trading period, denoted by \( R \), is shown in Eq. 9.
According to the investment risk theory, the power retailers hopes to maximize the expected return and minimize the corresponding risk, so the profit and risk can be expressed as a multi-objective planning model mathematically, and the most satisfactory optimization scheme is pursued between profit and risk. The optimization model of purchase and sale for power retailers considering renewable energy market and risks can be expressed in Eq. 10.

\[ Z = f(P_f, Q_n', Q_m', Q_n', Q_m', Q_r', Q_o) = \left\{ \begin{array}{c} \min \left( -F(P_f, Q_n', Q_m', Q_n', Q_m', Q_r', Q_o) \right) \\ \min R(Q_n', P_f, Q_m', Q_m') \end{array} \right\} \]  

(10)

Some conditions are used to constrain the objective function shown in Eq. 10. Power balance constraints is shown in Eq. 11. The constraints of market power are shown in Eq. 12 to Eq. 17, where \( Q_{n_{\text{min}}}^{f} \), \( Q_{n_{\text{max}}}^{f} \), \( Q_{m_{\text{min}}}^{f} \), \( Q_{m_{\text{max}}}^{f} \), \( Q_{n_{\text{min}}}^{r} \), \( Q_{n_{\text{max}}}^{r} \), \( Q_{m_{\text{min}}}^{r} \), \( Q_{m_{\text{max}}}^{r} \), \( Q_{n_{\text{min}}}^{o} \), \( Q_{n_{\text{max}}}^{o} \) and \( Q_{m_{\text{min}}}^{o} \), \( Q_{m_{\text{max}}}^{o} \) represent the upper and lower limits of the power levels at all levels of the market respectively. The constraints on renewable energy output is shown in Eq. 18. The price of sale is constrained as shown in Eq. 19, where \( P_{s_{\text{max}}}^{f} \) and \( P_{s_{\text{min}}}^{f} \) represent the upper and lower limits of the price of sale respectively. The constraints of the combination of the market is shown in Eq. 20, where \( \varepsilon_{\text{max}} \) and \( \varepsilon_{\text{min}} \) respectively represent the upper and lower limits of the proportion of power distribution in the medium and long-term market. Restriction of the capacity to absorb renewable energy is shown in Eq. 21, where \( \lambda_{\text{max}} \) and \( \lambda_{\text{min}} \) represent the upper and lower limits of the capacity to absorb renewable energy.

\[ D(t) = Q_n'(t) + Q_m'(t) + Q_r'(t) + Q_o'(t) \]  

(11)

\[ Q_{n_{\text{min}}}^{f} \leq Q_{n_{\text{min}}}^{f}(t) \leq Q_{n_{\text{max}}}^{f} \]  

(12)

\[ Q_{n_{\text{min}}}^{f} \leq Q_{n_{\text{max}}}^{f}(t) \leq Q_{n_{\text{max}}}^{f} \]  

(13)
\[ Q_{m}^{\text{min}} \leq Q_{m}^l(t) \leq Q_{m}^{\text{max}} \]  
(14)

\[ Q_{r}^{\text{min}} \leq Q_{r}(t) \leq Q_{r}^{\text{max}} \]  
(15)

\[ Q_o^{\text{min}} \leq Q_{o}(t) \leq Q_{o}^{\text{max}} \]  
(16)

\[ Q_{s}^{\text{min}} \leq Q_{s}(t) \leq Q_{s}^{\text{max}} \]  
(17)

\[ Q_{s}^{\text{min}} \leq Q_{s}(t) + Q_{o}(t) \leq Q_{t}(t) \]  
(18)

\[ P_{s}^{\text{min}}(t) \leq P_{s}(t) \leq P_{s}^{\text{max}}(t) \]  
(19)

\[ E_{\text{min}} \leq \frac{Q_{s}^{l}(t) + Q_{s}^{r}(t)}{D(t)} \leq E_{\text{max}} \]  
(20)

\[ \hat{\lambda}_{\text{min}} \leq \frac{\sum_{i=1}^{T}[Q_{s}^{l}(t) + Q_{s}^{r}(t)]}{\sum_{i=1}^{T}D(t)} \leq \hat{\lambda}_{\text{max}} \]  
(21)

Results and Discussion

Analysis of Pareto Front of the Purchase and Sale Strategy

The model established in this paper belonged to the multi-objective programming problem and had the complexity of multivariate and multi-constraint. NSGA-II was used to solve the problem in MATLAB through relevant historical data of a certain region. The population size (pop) was set to 2000 and the maximum evolution generation (gen) was set to 600.

Suppose there are 3 retailers. In Figure 1, the blue curve shows the Retailer 1 with renewable energy purchases. The red curve indicates that the Retailer 2, which is similar to the Retailer 1 but has a higher capacity to absorb renewable energy. The yellow curve indicates the Retailer 3 whose power purchase does not include renewable energy.

The Pareto front of the strategy solved by the optimization model established in this paper is shown in Figure 1, where the abscissa is the opposite of the profit and the ordinate is the risk. Then the curve can be understood as: the profit increases, the risk will gradually increase.

![Figure 1. Comparison of the Pareto fronts of three power retailers.](image-url)
Analysis of the Comparison of Different Types of Power Retailers

In the Figure1, comparing Retailer 1 and Retailer 2, the Pareto front of Retailer 2 is at the upper right of the Retailer 1, that is, in the pursuit of the same profit, the increase in the capacity to absorb renewable energy will increase certain risks. This is because the coefficient of the price risk element of renewable energy market is larger than traditional power market due to the uncertainty of the contribution of the renewable energy, which has led to a greater impact on the overall risk. In the case of Retailer 3, there is a point of intersection between the Retailer 2 and the Retailer 3. On the left side of the intersection, with the increase in the purchase of renewable energy, the risk and profit of the Retailer 2 are greater than that of the Retailer 3. On the right side of the intersection, the risk and profit of the Retailer 2 are smaller than those of the Retailer 3. This is mainly to benefit from the combination of power purchases in multi-level markets. It can be seen that the strategy proposed in this paper enjoys certain advantages in terms of profit and risk relative to the purchases that do not include renewable energy.

Analysis of Selling Price and Distribution of Power Purchase

The three points A, B, and C on the blue curve in Figure 1 are taken out for analysis. Point A is a radical strategy. This strategy pays more attention to pursuing more profits, so the risk is higher; Point C is a conservative strategy, which pays more attention to avoiding risks, so the profit obtained is lower; Point B is a balanced strategy, and its decision-making goal is between A and C, which is a relatively compromise strategy. The selling price of the three points A, B, and C in Figure 1 is shown in Figure 2. From Figure 2, the price of the radical type is generally the highest, while the conservative type is the lowest, and the balanced type is generally between the two. Point B is selected for further analysis of the distribution of power purchase, and the result is shown in Figure 3. It can be seen from Figure 3 that more power is allocated in the medium and long-term market during the price valley period. However, the power purchase in the medium and long-term market will be reduced and more power will be allocated to the spot market during the peak price period.

Conclusions

This paper studied the purchase and sale strategy for power retailers with renewable energy purchase considering risks. A multi-objective optimization model of purchase and sale for power retailers was established based on the theory of risk element transmission. The model was solved and the effectiveness of the purchase and sale strategy was verified by an example. The research in this paper can promote the marketization of renewable energy, promote the consumption of renewable energy and assist the decision-making of power retailers.

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