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The Influence of Risk Preference on the Game Behavior of Electricity Retailers

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Abstract: ***With the continuous promotion of China's electricity sales side reform, electricity retailers need to continuously optimize their decisions to adapt to the new market mechanism, therefore, it is of great significance to conduct corresponding strategic research. In this paper, the non-cooperative game with a limited number of electricity retailers is used to simulate the competitive market environment, and the multi-retailer game model is constructed considering conditional value-at-risk (CVaR). The retailer purchases electricity through the bilateral contract, centralized competitive trading, and day-ahead spot market, and conducts risk measurement based on CVaR; the interaction between electricity retailers and electricity customers is indirectly described by the Logit market share function. Finally, the simulation case is designed to verify the effectiveness of the model and analyze the influence of risk preference on the game behavior of electricity retailers, it is concluded that the more risk-averse the electricity retailer is, the more inclined they are to set higher retail electricity price and tend to purchase less electricity from the day-ahead spot market with more price fluctuations while obtaining lower market share and expected profit.***

Keywords: Retail electricity market, Multi-retailers, Conditional value at risk, Game

1. Introduction

In March 2015, a clear reform of the electricity sales side was proposed in China [1]. In the context of the new electricity reform, a large amount of social capital has entered the retail electricity market, and electricity retailers will face new opportunities and challenges. Therefore, in the context of increasingly fierce competition in the retail electricity market, it is of great significance to conduct corresponding strategic research.

For electricity retailers, risk management has become one of the most urgent issues to be solved in the operating process. At present, the risk assessment methods applied in the electricity market include value at risk (VaR) [2], conditional value at risk (CVaR) [3] and information gap decision theory (IGDT) [4]. Among them, VaR cannot accurately reflect the degree of loss of asset returns under abnormal market conditions, and can only measure the loss information at the quantile, ignoring extreme losses beyond the quantile, and does not have subadditivity. In contrast, CVaR, as a consistent risk measurement indicator, overcomes the deficiency that VaR does not meet the consistency of risk measurement and has been widely used in risk assessment of electricity retailers. Literature [5]-[7] optimize the electricity retailer's electricity purchase and sales decisions by considering CVaR risk constraints and maximizing expected profits. In the literature [8]-[10], CVaR theory is applied to measure the uncertainty of customer demand-side load, taking into account the user demand response (DR). In the literature [11], a two-layer game model between the electricity retailer and residential customers is established based on the construction of the electric energy utility function model and the electricity price model, for the electricity retailer, the set pricing scheme guides the load demand of customers and effectively relieves the total load during peak hours. For customers, it reduces the cost of purchasing electricity and improves customer benefits. However, the competitive game relationship among multiple electricity retailers is not considered. The literature [12]-[13] obtained Nash equilibrium by establishing the game model under incomplete information. Among them, literature [13] adopts the Bertrand oligopoly competition model to establish the game model for retailers to participate in bidding transactions in the retail market but does not optimize the power purchase and sale strategies of retailers.

In response to the shortcomings in the aforementioned literature, this paper abstracts the retail electricity market as a complex adaptive system formed by entities such as electricity retailers and electricity consumers and constructs the multi-retailer game model to simulate the competitive market environment. Electricity retailers purchase electricity through the bilateral contract, centralized competitive trading, and day-ahead spot market, and sell it to electricity consumers through fixed price contracts; electricity consumers freely choose to purchase electricity among multiple electricity retailers, and their behavior is characterized by the Logit market share function. Based on CVaR and various power purchase channels, multiple electricity retailers continuously optimize their strategies during the game period, and reach the market equilibrium after multiple rounds of the game. A simulation case is designed to verify the effectiveness of the proposed model and analyze the laws of electricity retailers under different risk preferences, in order to provide strategic support for electricity retailers and provide references for the improvement and development of the retail electricity market.

2. Multi-retailer Game Framework

Electricity retailers purchase electricity from the wholesale electricity market and then develop sales strategies to resell electricity to customers and profit from it. In the game process, each electricity retailer dynamically adjusts its optimal decisions to maximize its profits, the decision variables are bilateral electricity purchase, centralized competitive trading electricity purchase, day-ahead spot electricity purchase, and retail price; electricity consumers calculate consumer utility based on the retail prices and services of multiple retailers, and determine the market share of the retailer through the Logit discrete choice model, which in turn affects the retailer's profit and risk. After multiple rounds of the game, the market equilibrium is reached. Taking five retailers as an example, the framework of the multi-agent game in the retail electricity market is shown in Figure 1.

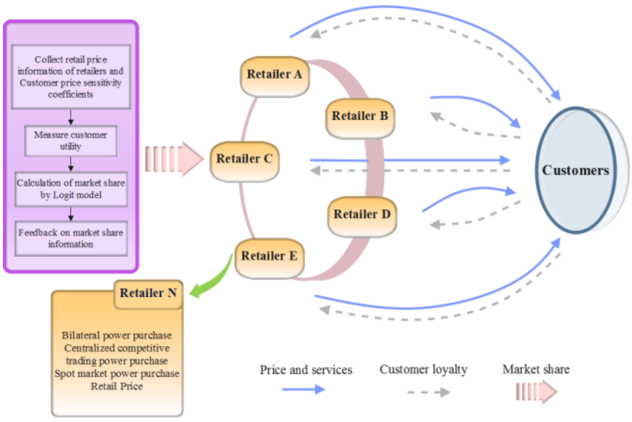

Figure 1: Schematic diagram of the multi-agent game framework in the retail electricity market

3. Game Model of Purchasing and Selling Electricity for Multi-retailers Considering CVaR

3.1 Cost Model

The cost of the electricity retailer includes the cost of purchasing electricity and operating cost. The electricity retailer adopts three power purchase channels: bilateral contract, centralized competitive trading, and day-ahead spot market. The price of the bilateral contract is generally fixed, while the price of electricity traded in centralized competitive trading and day-ahead spot market is volatile and difficult to predict accurately. Therefore, in this paper, it is assumed that the centralized competitive trading price and the day-ahead spot price in a unit period follow the normal distribution, and the Monte Carlo simulation method and backward reduction technology are used to generate the trading price in 800 scenarios.

$$\Omega=\left\{\left\{\lambda^{CB}(t,w),\lambda^{DA}(t,\omega)\right\},\pi(w)\right\} \quad \omega=1,\cdots,N_{\Omega} \tag{1}$$

$$\sum_{\omega=1}^{N_{\Omega}}\pi(w)=1 \tag{2}$$

$$\begin{aligned}C_{i,j}^{EP}(w)=&\sum_{t=1}^{T}[\lambda_i^{FC}P_{i,j}^{FC}(t)+\lambda^{CB}(t,w)P_{i,j}^{CB}(t)\\&+\lambda^{DA}(t,\omega)P_{i,j}^{DA}(t)] \quad \forall i\in I \quad \forall j\in J \quad \forall\omega\in\Omega\end{aligned} \tag{3}$$

$$\begin{aligned}C_{i,j}^{BS}=&C_i^{COS}+c_i^{Fixed}+m_i\cdot\sum_{t=1}^{T}[P_{i,j}^{FC}(t)+P_{i,j}^{CB}(t)+P_{i,j}^{DA}(t)]\\&-k_i\times[\sum_{t=1}^{T}[P_{i,j}^{FC}(t)+P_{i,j}^{CB}(t)+P_{i,j}^{DA}(t)]]^2 \quad \forall i\in I \quad \forall j\in J\end{aligned} \tag{4}$$

where $\pi(w)$ is the probability of each price scenario; λ_i^{FC} is the electricity price in the bilateral contract; $\lambda^{CB}(t,\omega)$ and $\lambda^{DA}(t,\omega)$ denote the prices in the centralized competitive trading and spot market under the scenario w at time period t; $P_{i,j}^{FC}(t)$, $P_{i,j}^{CB}(t)$ and $P_{i,j}^{DA}(t)$ are the amount of power purchased by the retailer i in the bilateral contract, centralized competitive trading and spot market in the jth round of gaming at time period t; m_i is the initial unit cost of the retailer's electricity purchase and sale business; k_i is the rate of decrease in the unit cost; c_i^{fixed} is the fixed operating cost of the retailer i; C_i^{COS} is the service cost invested by the retailer i; $C_{i,j}^{BS}$ is the total operating cost of the retailer i in the jth round game.

3.2 Income

Customers can freely choose among multiple electricity retailers based on their needs to obtain more favorable electricity prices and more comprehensive services. Using the Logit function as the market share function to describe the relationship between the retail price of electricity retailers and the proportion of customers they acquire, the income of the electricity retailer is obtained as follows:

$$\begin{cases}S_{i,j}^{FIX}=\dfrac{e^{u(\lambda_{i,j}^{FIX})}}{e^{u(\lambda_{i,j}^{FIX})}+e^{u(\lambda_{-i,j-1}^{FIX})}}\\u(\lambda_{i,j}^{FIX})=m-n\lambda_{i,j}^{FIX}\\E_{i,j}^{FIX}=\sum_{t=1}^{T}[\lambda_{i,j}^{FIX}P(t)S_{i,j}^{FIX}]\end{cases} \tag{5}$$

where $\lambda_{i,j}^{FIX}$ the optimal retail price set by the electricity retailer i in the jth round game; $u(\lambda_{i,j}^{FIX})$ is the market share utility when customers choose the retailer i in the jth round game, $\lambda_{-i,j-1}^{FIX}$ is the optimal retail price set by the rivals of the electricity retailer i in the last round of the game; m is the fixed utility coefficient and n is the electricity price sensitivity coefficient of the customer to the retailer i corresponding to the service cost invested by the retailer i; $P(t)$ is the total load of the customers at time period t.

3.3 Risk Measurement Model

The CVaR risk measurement model is used to measure the risk in the process of purchasing and selling electricity by electricity retailers. CVaR is the average of the losses that could be incurred by a portfolio of assets over a given time period at a certain confidence level that exceeds the VaR and can be used to measure the extreme losses of a retailer at the confidence level.

$$CVaR_{\beta}=VaR_{\beta}+\frac{1}{1-\beta}\sum_{\omega=1}^{\Omega}\{\pi(\omega)[f(x,r,\omega)-VaR_{\beta}]^{+}\} \tag{6}$$

$$[f(x,r,\omega)-VaR_{\beta}]^{+}=\begin{cases}f(x,r,\omega)-VaR_{\beta}, & f(x,r,\omega)\geq VaR_{\beta}\\0 & ,f(x,r,\omega)<VaR_{\beta}\end{cases} \tag{7}$$

where β is the confidence level; VaR_{β} denotes the value-at-risk when the confidence level is β; $f(x,r,\omega)$ denotes the loss function of the electricity retailer in the scenario w, and it takes the opposite of the actual profit calculated for each scenario.

3.4 Objective Function and Constraints

The objective of the retailer is to maximize the expected profit while keeping the risk minimized. The retailer's objective function is expressed as:

$$Max\left\{\sum_{w=1}^{\Omega}\pi(w)\cdot[E_{i,j}^{FIX}-C_{i,j}^{EP}(w)-C_{i,j}^{BS}]\right\} \tag{8}$$

Subject to:

$$CVaR_{\beta,i}\le risk_i^{\max} \tag{9}$$

$$P(t)S_{i,j}^{FIX}=P_{i,j}^{FC}(t)+P_{i,j}^{CB}(t)+P_{i,j}^{DA}(t) \tag{10}$$

$$k_{\min}P(t)S_{i,j}^{FIX}\le P_{i,j}^{FC}(t)\le k_{\max}P(t)S_{i,j}^{FIX} \tag{11}$$

$$\lambda_{\min}^{FIX}\le\lambda_{i,j}^{FIX}\le\lambda_{\max}^{FIX} \tag{12}$$

where $risk_i^{\max}$ is the maximum value of the risk; $k_{\max}$ and $k_{\min}$ are the highest and lowest percentage of electricity purchased bilaterally to the fixed price retail contracted electricity signed between the retailer and the customers, equal 90% and 30% respectively; $\lambda_{\min}^{FIX}$ and $\lambda_{\max}^{FIX}$ are the lowest and highest retail price of electricity retailers, equal 300 CNY/MWh and 800 CNY/MWh respectively.

4. Simulation and Analysis

To explore the influence of different risk preferences of electricity retailers on their game behavior, a regional retail electricity market in Guangdong Province, China, is studied for an optimization time period with a customer load of 1500 MWh. The expectation and standard deviation of the power purchase side price are referred to the actual trading data of the Guangdong electricity market in 2022. The centralized competitive trading price per unit time period satisfies a normal distribution with expectation μ_{CB} and variance σ_{CB}^2, and the day-ahead spot price obeys a normal distribution with expectation μ_{DA} and variance σ_{DA}^2. Based on the price fluctuations of centralized competitive trading and day-ahead spot market in the actual market, μ_{CB} equals 450 CNY/MWh, μ_{DA} equals 415 CNY/MWh, σ_{CB} and σ_{DA} are taken as 10% and 20% of the corresponding expect price respectively. The price of electricity decomposed into this period in the bilateral contract is fixed as a constant, taking 500 CNY/MWh. There are five electricity retailers A, B, C, D, and E available for customers in this region, The upper limits of the risk constraints of the five retailers A, B, C, D and E are set to decreasing orders of 17000, 3500, -4000, -7500, and -10000 respectively. In addition, each retailer has the same parameters such as operating cost and bilateral electricity price. On this basis, the equilibrium of each electricity retailer under increasing risk aversion of the electricity retailer is obtained as shown in Figure 2 - Figure 5.

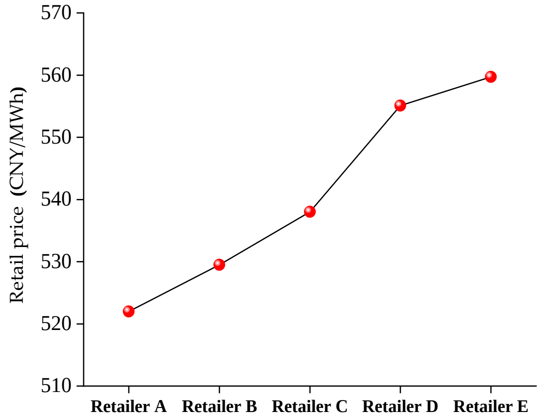

Figure 2: Retail prices of the five electricity retailers with different risk preferences

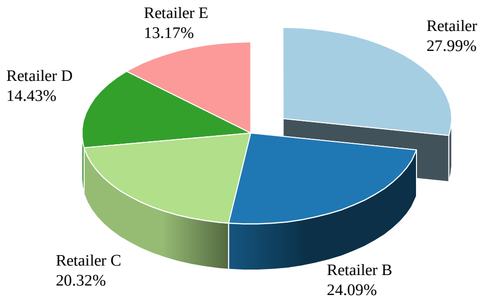

Figure 3: Market share of the five electricity retailers with different risk preferences

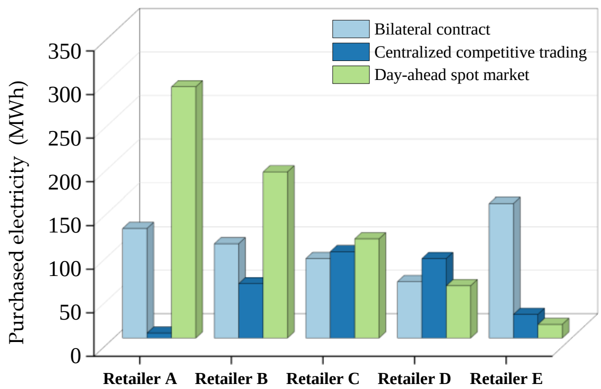

Figure 4: Electricity purchased in different markets of the five electricity retailers with different risk preferences

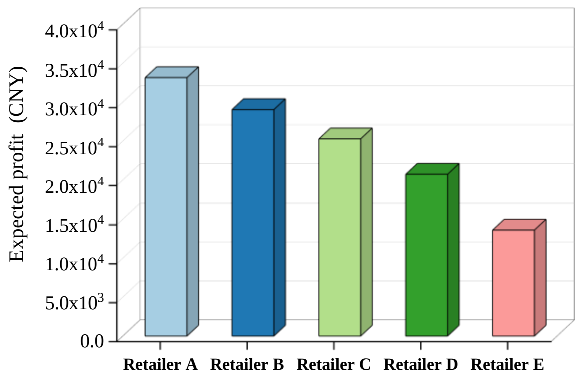

Figure 5: Expected profits of the five electricity retailers with different risk preferences

From the simulation results, it can be seen that as the risk aversion of electricity retailers increases, the proportion of power purchase in the medium- and long-rm market becomes larger, the proportion of power purchase in the day-head spot market becomes smaller and the expected profit becomes lower, which indicates that the electricity retailer use the medium- and long-term market with less price fluctuations to avoid market risks. However, since the expected electricity prices of the bilateral contract and centralized competitive trading are higher than the expected price of the day-ahead spot market, the expected profit of the electricity retailer will also decrease. In addition, with the increase of risk aversion of the electricity retailer, the amount of electricity purchased in the centralized competitive trading increases and then decreases. which can be interpreted as that the electricity retailer, while pursuing low risk and still obtaining higher profits, will reduce their market share in the day-ahead market with price fluctuations and high profits, and shift share to the centralized competitive trading with higher but less volatile electricity prices, and the amount of electricity purchased in the centralized competitive trading will increase; when risk aversion increases to a certain level, the centralized competitive trading can't meet the requirement of the electricity retailer for low risk, the electricity retailer will shift share from the centralized competitive trading to the bilateral contract with the highest and the most stable price, and the amount of electricity purchased in the centralized competitive trading will be reduced.

The retailer with high risk aversion will hedge risk by increasing the proportion of power purchased in the medium- and long-term market, which also leads to higher unit power purchase costs for the retailer, and the retailer chooses to increase the retail price to make up for the cost when maximizing its profit, however, the high retail price will cause customers to switch to other retailers to purchase electricity, leading to a decrease in market share for the retailer, instead making the final expected profit lower, which suggests that high profits for electricity retailer generally need to be accompanied by high risk.

5. Conclusion

The retail electricity market is a complex adaptive system composed of multiple entities. In this paper, the multi-retailer game model is constructed, and CVaR is adopted to measure the risk of electricity retailers in the process of purchasing and selling electricity. Finally, through simulation analysis of the influence of risk preferences of electricity retailers on their game behavior, it can be concluded that the electricity retailer with high risk aversion will strongly avoid purchasing electricity from the day-ahead spot market with high price fluctuations and tend to develop high retail price, while the retailer that enjoys taking risks tends to lower its retail price to occupy more market share and gain higher expected profits while bearing high risks.

References

[1] The State Council of the Central Committee of the Communist Party of China, " A Number of Views on Further Deepening the Reform of the Power System," March. 15, 2015. [Online]. Available: http://fjb.nea.gov.cn/pufa_view.aspx?id=31434. [Accessed: May. 16, 2023].

[2] B. Jie, X. Qin, W. Zhongrong, “Research on optimized purchasing strategy and risk management in electricity market,” 2018 China International Conference on Electricity Distribution (CICED), pp. 2714-2717, 2018.

[3] R. T. Rockafellar, S. Uryasev, “Optimization of conditional value-at-risk,” Journal of risk, II, pp. 21-42, 2000.

[4] C. J. Shieh, I. Pustokhina, A. A. Rudenko, S. A. Sedov, O. Y. Nedorezova, A. Anderson, “Application of robust information game decision theory for risk-assessment problem in large scale users,” ISA Transactions, CXVI, pp. 167-181, 2021.

[5] X. Huang, X. Wang, L. Chen, C. Ye, “Optimal portfolio strategies of purchasing electricity for electricity company based on distributional robust CVaR,” IOP Conference Series: Earth and Environmental Science, pp. 012200, 2020.

[6] J. Yang, J. Zhao, F. Wen, Z. Dong, “A Framework of Customizing Electricity Retail Prices,” IEEE Transactions on Power Systems, XXXIII (3), pp. 2415–2428, 2018.

[7] E. Çanakoğlu, E. Adıyeke, “Comparison of electricity spot price modelling and risk management applications,” Energies, XIII (18), pp. 4698, 2020.

[8] J. Hou, Z. Zhang, Z. Lin, L. Yang, X. Liu, Y. Jiang, C. He, J. Li, K. Wang, W. Zhang, Y. Ding, W. Wen, “An energy imbalance settlement mechanism considering decision-making strategy of retailers under renewable portfolio standard,” IEEE Access, VII, pp. 118146–118161, 2019.

[9] M. J. Salehpour, S. M. M. Tafreshi, “The effect of price responsive loads uncertainty on the risk-constrained optimal operation of a smart micro-grid,” International Journal of Electrical Power & Energy Systems, CVI, pp. 546-560, 2019.

[10] A. R. Jordehi, V. S. Tabar, S. A. Mansouri, M. Nasir, S. M. Hakimi, S. Pirouzi, “A risk-averse two-stage stochastic model for planning retailers including self-generation and storage system,” Journal of Energy Storage, LI, pp. 104380, 2022.

[11] Z. M. Fadlullah, D. M. Quan, N. Kato, I. Stojmenovic, “GTES: An Optimized Game-Theoretic Demand-Side Management Scheme for Smart Grid,” IEEE Systems Journal, VIII (2), pp. 588–597, 2014.

[12] A. Talwariya, P. Singh, M. Kolhe, “A stepwise power tariff model with game theory based on Monte-Carlo simulation and its applications for household, agricultural, commercial and industrial consumers,” International Journal of Electrical Power & Energy Systems, CXI, pp. 14–24, 2019.

[13] C. Zhao, S. Zhang, X. Wang, X. Li, L. Wu, “Game analysis of electricity retail market considering customers' switching behaviors and retailers' contract trading,” IEEE Access, VI, pp. 75099–75109, 2018.