Research on Optimized Operational Strategy of Electricity Distributors and Retailers Considering Opening Incremental Distribution Network

Bin Ye[1, a, *], Yu Chen[1, b], Liuzhu Zhu[2, c], Xijun Ren[1, d] and Xiaowei Zhang [3, e]

[1] State Grid Anhui Electric Power Company Economic and Technical Research Institute, Hefei 230022, Anhui Province, China.

[2] State Grid Anhui Electric Power Company, Hefei 230022, Anhui Province, China.

[3] Shandong Ohm Power Technology Co., Ltd., Taian 271000, Shandong Province, China.

[a, *] hoversoju@163.com, [b] wlucptwa2291@163.com, [c] gtbduezjmq806725@126.com, [d] hbgpf4@163.com

[e] vitashinezhang@163.com

Keywords: Incremental Distribution Network Business Liberalization; Electricity Distributors and Retailers; Electricity Purchase and Sale Strategy; Conditional Value at Risk (CVaR); Demand Response.

Abstract: The Operational Strategy of electricity distributors and retailers is affected by government policy, load prediction and power supply reliability under the background of opening incremental distribution network. This paper puts forward the power supply reliability evaluation model of the distribution network based on fuzzy set theory. The electricity purchase and sale strategy model of electricity distributors and retailers considering demand response is proposed. Then, a two-stage optimization model of electricity purchase and sale strategy considering risk is established. The first stage is aimed at minimizing the main the risk cost of electricity purchase and sale, expecting profit and power supply reliability as constraints, and making decisions on the purchase of electricity. The second stage analyzes the decision of the electricity purchase strategy considering the feasibility of the inner optimization results and the investment preference of the social capital. The simulation results show that the interruptible load can help reduce the risk of power supply reliability after considering the demand response and different purchasing power sources and risk preferences will affect the expected profit of electricity distributors and retailers.

1. Introduction

Social capital can obtain the construction right and electricity sale right of the distribution network through competition in some countries that have already undergone electricity market reforms, such as China. Correspondingly, the structure of the incremental distribution network and the electricity purchase and sale strategy will lead to uncertainty in the incremental distribution network business. Therefore, it is necessary to focus on the risk analysis in this process.

There are many research results on the risk assessment and management in the electricity market. Literature [1] outlines the risk assessment methods for power trading, and introduces typical risk assessment methods such as Value at Risk (VaR) and Conditional Value at Risk (CVaR). Literature [2] proposes the optimization of power investment portfolio of the distribution network. Literature [3] uses a hybrid probability assessment method based on adaptive importance sampling and sequential importance sampling to conduct risk assessment of electricity prices.

Many scholars have analyzed the risks of electricity purchase and sale. In Literature [4], a regression method is proposed to measure the electricity price caused by multi-fractal distribution price fluctuation. In addition, there are many studies on the risk analysis [5-7] and the optimal strategy [8-10] of electricity purchase and sale. However, the risk factors considered are relatively simple, such as only assessing the quotation risk [6], price risk [7-9] and ignoring the risk factor [11].

This paper analyzes the risks in the investment and operation process of the distribution company under the environment of the incremental distribution network business. A two-stage risk assessment model was established with CVaR as a market risk measurement indicator. The first stage proposes an electricity purchase and sale portfolio model that minimizes operational risk costs. The second stage considers the feasibility of the inner optimization results and the investment risk preference, and proposes an investment risk decision model.

2. Risk Assessment Model of Electricity Distributors and Retailers

A. *Investment Risk Assessment Model*

Electricity distributors and retailers is in a complete market environment and will directly face the risk factors in the investment market. An investment risk assessment method based on fuzzy theory and incremental cash flow can assess and control uncertain risk factors in the investment process. Uncertain factors such as the environment and natural disasters cannot be predicted by historical data, and can be evaluated by expert experience using triangular fuzzy numbers.

Set U is a fuzzy set on a given universe, for $\forall x \in U$, there is a membership degree $\mu(x) \in [0,1]$ corresponding to it, and $\mu(x)$ is the membership function of *x*. If the amount of ambiguity given by the expert is a three-valued judgment, such as the lowest possible value *l*, the most likely value *m*, and the highest possible value *u*, it is called a triangular fuzzy number (TFN), which is expressed as (*l, m, u*), and its membership function is expressed as:

$$\mu_M(x) = \begin{cases} \dfrac{x-l}{m-l}, x \in [l,m] \\ \dfrac{x-u}{m-u}, x \in [m,u] \\ 0, otherwise \end{cases} \quad (1)$$

The ambiguous risk factors of investment incremental distribution network are mainly composed of environmental risks, including political and economic risk PR and natural disaster risk NDR. The political and economic risks are mainly derived from the changes in electricity sales in the macroeconomic background of the corresponding political and economic, and can be described by the proportion of increased electricity sales and the triangular fuzzy number can be expressed as $(PR_{\min}, PR_c, PR_{\max})$. The risk of natural disasters mainly comes from natural disasters, such as typhoon, snow disasters, earthquakes, etc. The investment of incremental distribution network can enhance the tolerance to natural disasters to a certain extent, so the NDR can be described by the reduced natural disaster loss value, and the triangular fuzzy number can be expressed as $(NDR_{\min}, NDR_c, NDR_{\max})$. The budget for investment costs also has some uncertainty and represented by triangular fuzzy numbers. Its membership function can be expressed as $(IC_{\min}, IC_c, IC_{\max})$ in the range of "IC_c".

B. *Risk Assessment of Electricity Purchase and Sale Strategy*

The profit from the purchase and sale of the electricity company is *p*, which is the difference between the electricity sales revenue R and the electricity purchase cost C.

$$p = R - C = \sum_{t \in T} (\sum_{j \in \Omega} \delta(j) \lambda_{s,t}(j) P_{s,t}(j)) - \sum_{t \in T} (\sum_{i \in \Lambda} \lambda_{c,i} P_{c,i} + \sum_{j \in \Omega} \delta(j) \lambda_{DA,t}(j) P_{DA,t}(j)) \quad (2)$$

where $\delta(\mathrm{j})$ is the probability of occurrence of scene *j*; $\Omega = [1, 2, ..., J]$ is used to describe the volatility and uncertainty of the spot market price; $\lambda_{s,t}(\mathrm{j})$ is the price of electricity sold at time t in scene j; $P_{s,t}(j)$ is the electricity sold at time t in scene j; $\lambda_{c,i}$ is the i-th equivalent electricity price of the medium-long term bilateral contract; $P_{c,i}$ is the contract electricity of the i-th bilateral contract; $\lambda_{DA,t}(j)$ and $\lambda_{DA,t}(j)$ is the electricity purchase price and electricity purchase price at time t in scene j in the spot market.

A sample including J group of electricity sales profit is generated by Monte Carlo simulation and expressed as $p_1, p_2, ..., p_J$. The CVaR [12] corresponding to the risk value of electricity sales profit is used to assess the difference between the actual electricity sales profits and the expected electricity sales profits can be expressed by the following formula:

$$CVaR(p) = VaR(p) + \frac{1}{J(1-\beta)} \cdot \sum_{j=1}^{J} \max\left\{0, E(p) - P_j - VaR(p)\right\} \tag{3}$$

In the formula, p is the sales profit variable of J-dimension; $VaR(p)$ is the VaR value under the constraint of a certain confidence level and risk level; $\beta \in (0,1)$ is the confidence level of CVaR.

The expected value of p is expressed as:

$$E(p) = \frac{1}{J}\sum_{j=1}^{J} p_j \tag{4}$$

By introducing dummy variables $z_j\left(j = 1,2,...J\right)$, the minimum value of CVaR can be found using a linear programming model without calculating the VaR value.

$$\begin{aligned} &\min F\left(p,\alpha\right) = \alpha + \frac{1}{J(1-\beta)}\sum_{j=1}^{J} z_j \\ &s.t. z_j \geq 0 \\ &z_j \geq E(p) - p_j - \alpha \end{aligned} \tag{5}$$

C. *Power Supply Reliability Risk Assessment Considering Demand Response*

Considering the interruptible load, the risk cost of purchasing power reserve capacity for electricity distributors and retailers can be calculated by the following process.

There are N power consumers in the power distribution area, of which K can be interrupted. The power supply reliability requirement of each consumer is SR_n, and the interruptible load of consumers participating in the demand response is $Q_{DR,k}$. The price of spare capacity consists of capacity cost and electricity cost. The former needs to be paid regardless of whether it is called or not; the latter needs to be paid when it is called. The capacity price $P_c (Q_s)$ and the electricity price $P_e (Q_s)$ are generally positively correlated with the reserve power Q_s.In order to measure the risk of fluctuations in $P_c(Q_s)$ and $P_e(Q_s)$, a large enough sample capacity can be simulated to obtain an average simulated positive deviation σ_c and σ_e. The risk cost of electricity distributors and retailers which purchase the spare capacity from the reserve market is expressed as:

$$C_{SC} = \left[P_c\left(Q_s\right) + \sigma_s + \rho_e\left(P_e\left(Q_s\right) + \sigma_e\right)\right] \cdot Q_s \tag{6}$$

where ρ_e is the probability that the spare capacity is called; Q_s is the reserve power purchase.

The total cost of the compensating company to compensate for the interruptible load is expressed as:

$$C_{DR}=\sum_{k=1}^{K}\rho_k\left(\lambda_{DR,k}Q_{DR,k}^2+\mu_{DR,k}Q_{DR,k}\right) \tag{7}$$

where ρ_k is the probability that the interruptible load is called; $\lambda_{DR,k}$ and $\lambda_{DR,k}$ is the coefficient related to the compensated electricity price; $Q_{DR,k}$ is the interruptible load.

After the implementation of the demand response by electricity distributors and retailers, the equivalent total risk cost of purchasing the spare capacity for generating electricity is expressed as:

$$C_R=C_{SC}+C_{DR} \tag{8}$$

3. Two-stage Risk Assessment Model

Considering the impact of investment environment risk, purchase and sale electricity risk and power supply reliability risk, a two-stage risk optimization evaluation model is established.

D. *Objective function*

The first stage aims at maximizing the profit from purchasing and selling electricity, including the actual cost of electricity purchase and the equivalent total risk cost of purchasing spare capacity, as shown in equation (9).

$$\pi_p=\max\left(p-C_R\right) \tag{9}$$

The comprehensive risk assessment in the second stage uses Incremental Cash Flow (ICF) as a risk assessment indicator for each investment plan. The Net Present Value (NPV) can be used to calculate the difference between the discounted value of future cash flows and the investment cost.

$$NPV=\sum_{n=1}^{N}\frac{C_n}{\left(1+r\right)^n}-C_0 \tag{10}$$

where NPV is the net present value; C_0 is the initial investment amount; C_n is the *n*-year cash flow, r is the discount rate; N is the life cycle of the investment project.

Considering the probabilistic risk of different purchase and sale combinations under different risk preferences and fuzzy risk factors, The Net Present Value is used to calculate the profitability of investment projects during the investment period. It can be obtained that the profit of the investment incremental distribution network in the evaluation period is as shown in Equation (11).

$$NPV=\sum_{n\in N}\left[\left(p*\left(1+PR\right)^n-C_R-\chi CVaR\left(p\right)\right)+\left(PND*NDR\right)\right]/\left(1+r\right)^n-IC \tag{11}$$

where χ is the risk preference coefficient of the electricity distributors and retailers; r is the discount rate; n=[1,2,..., N] is the evaluation period; *PND* is the probability of natural disaster occurrence; *NDR* is the reduced natural disaster loss; *IC* is the initial investment cost.

E. *Constraints*

3.1 Power Balance Constraints

Electricity purchases and electricity sales need to balance.

$$P_{s,t}=\sum_{i\in\Lambda}P_{c,i}+P_{DA,t}+P_{DA,t} \tag{12}$$

3.2 CVaR Risk Constraints

Expected risk of loss of profits is bound to a certain extent.

$$\begin{aligned} &\alpha + \frac{1}{J(1-\beta)}\sum_{j=1}^{J} z_j \le \omega \\ &z_j \ge 0 \\ &z_j \ge E(p) - p_j - \alpha \end{aligned} \tag{13}$$

where p is the sales profit variable of J-dimension; J is the total number of samples; $z_j\left(j=1,2,...J\right)$ is the dummy variable; α is the VaR variable under the constraint of certain confidence level and risk level; β and ω is the confidence level and constraint value of CVaR; $E(p)$ is the expected value of p.

3.3 Power Supply Reliability Constraints

After purchasing spare capacity, the power supply reliability must be greater than the consumer's minimum reliability SR_{min}, and the consumer's highest reliability constraint SR_{max} is satisfied with a certain confidence level ρ.

$$1 - P\left(Q_h > Q_{h,p} + Q_s + \sum_{k=1}^{K} Q_{DR,k}\right) \ge SR_{\min} \tag{14}$$

$$1 - P\left(Q_h > Q_{h,p} + Q_s + \sum_{k=1}^{K} Q_{DR,k}\right) \ge \rho \cdot SR_{\max} \tag{15}$$

where Q_h is the actual maximum load; $Q_{h,p}$ is the predicted maximum load.

3.4 Transmission Capacity Constraints

Transmission capacity constraints, including load capacity and spare capacity, do not exceed the maximum transmission capacity of the load line $TR_{\max}$.

$$Q_h + Q_s \le TR_{\max} + \sum_{k=1}^{K} Q_{DR,k} \tag{16}$$

4. Simulation

The operational risk of incremental electricity distributors and retailers is assessed by data from a US electricity market. The electricity price data of the market on a typical day is taken as the spot market electricity price, which is shown in Figure 1. The average spot market price is the average value, and the "3σ criterion" is used to simulate the generation of 200 scenes [10]. The predicted load curve of consumers is shown in Figure 2.

The information on bilateral contracts and interruptible load contracts is shown in Table 1, including the peak load period (9:00-11:00, 14:00-19:00), medium load period (6:00-9:00, 11:00-14:00, 19:00-22:00), low load period (0:00-6:00, 22:00-24:00).The reserve market capacity price is 24$/MWh and the fluctuation deviation is 1.62$/MWh. The electricity price is $P_e(Q_s) = 66.94 + 1.8 * Q_s$ and fluctuation deviation is 3.21$/MWh.

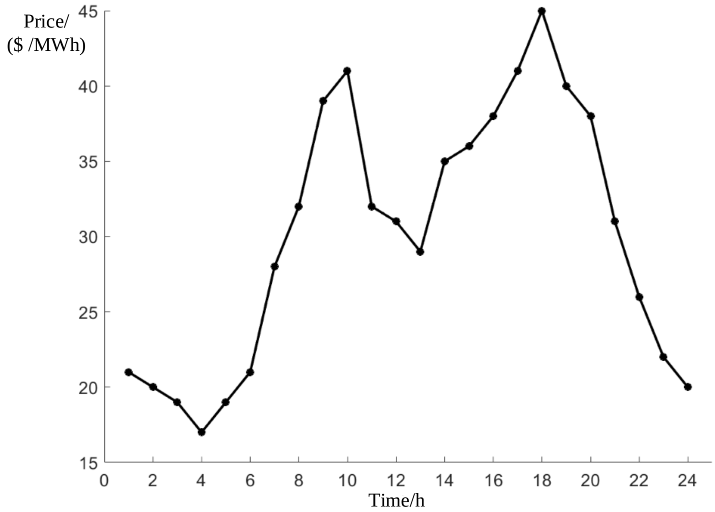

Figure 1. Benchmark value of spot market price.

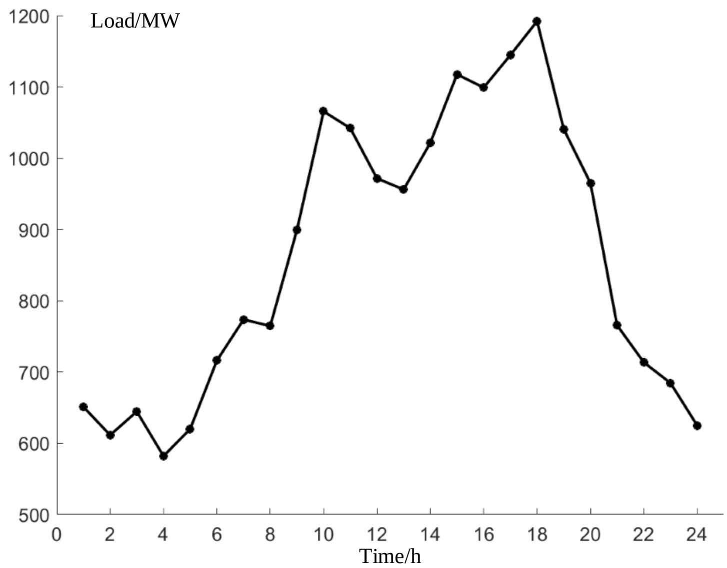

Figure 2. Load forecasting curve.

Table 1. Electricity market contract parameters.

		bilateral contract	**Interruptible load contract**
Peak load period	Contract price($/MWh)	52.8	56.2
	Electricity upper limit (MWh)	720	10
Medium load period	Contract price($/MWh)	36.6	38.4
	Electricity upper limit (MWh)	520	8
Low load period	Contract price($/MWh)	23.3	/
	Electricity upper limit (MWh)	460	/

F. Risk Assessment of Stage 1

Considering the demand response, the system's power supply reliability risk cost is shown in Table 2, and the confidence level ρ is 0.7. Comparing the capacity cost and the electricity cost, it can be seen that in order to maintain the same power supply reliability, the interruptible load can reduce the cost of spare capacity. In this scenario, the risk cost of spare capacity is reduced by 22.44%.

When the confidence level ρ increases, the cost of electricity decreases obviously, which is shown in Figure 3. When the confidence level gets higher, the distributors will pay more attention to the consumer's electricity supply reliability requirements, and will purchase more spares capacity to avoid electricity shortages. With the confidence level increasing, the decline of the electricity purchase cost will also get increasing when demand response is considered.

Table 2. Comparison of risk cost in purchasing spare capacity.

	No demand response	**Demand response**
Purchases in reserve market/MWH	619.97	477.97
Interruptible load/MWH	/	142.00
Capacity cost/$*$10^3$	15.88	12.25
Electricity cost/$*$10^3$	11.07	8.67
Total risk cost/$*$10^3$	26.96	20.91

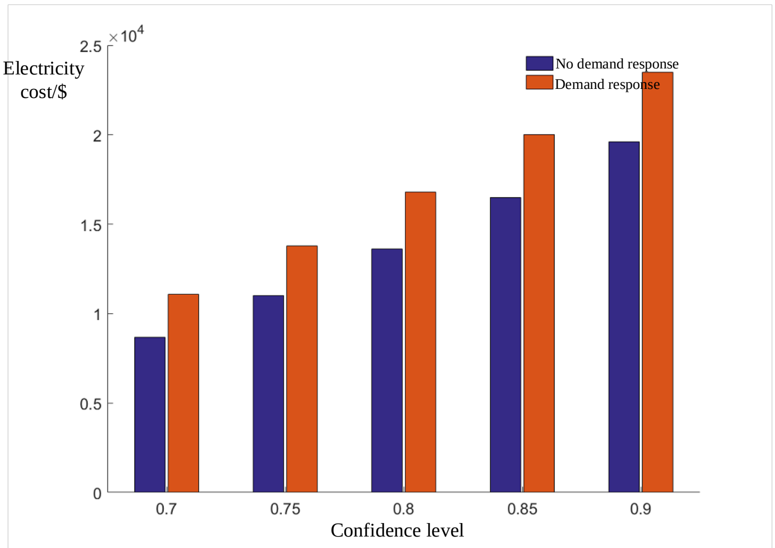

Figure 3. Comparison of spare electricity cost considering demand response.

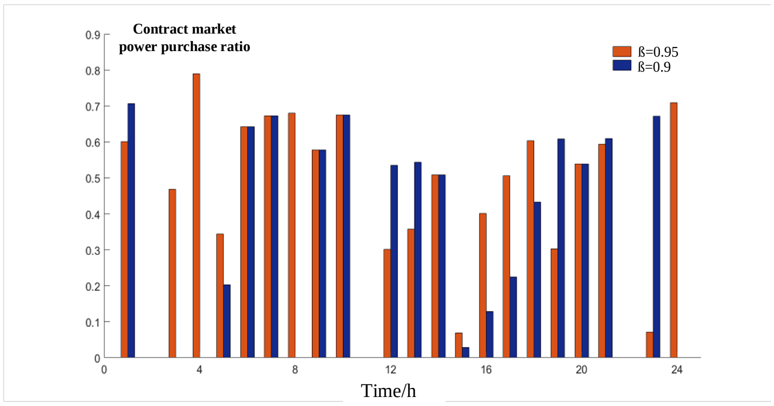

Figure 4. Optimal contract market power purchase ratio.

Under the same CVaR constraint, the optimal power purchase ratio of the contract market in one day is shown in Figure 4 when the confidence level β of CVaR is 0.9 and 0.95 respectively, and the remaining electricity is purchased from the spot market. It can be seen from the figure with the increasing of β, the proportion of power purchase in the contract market also increases, which means that the sellers prefer to choose a strategy with low profit and low risk. The proportion of electricity purchases in the two periods is also different. During the peak period, such as the period of 14-19, the proportion of contracted electricity purchases with β=0.95 is significantly higher than β=0.9. The price of electricity is high during the peak load hours, and the distributors prefer choosing the contract purchases to buying electricity in the spot market because of the aversion of risk.

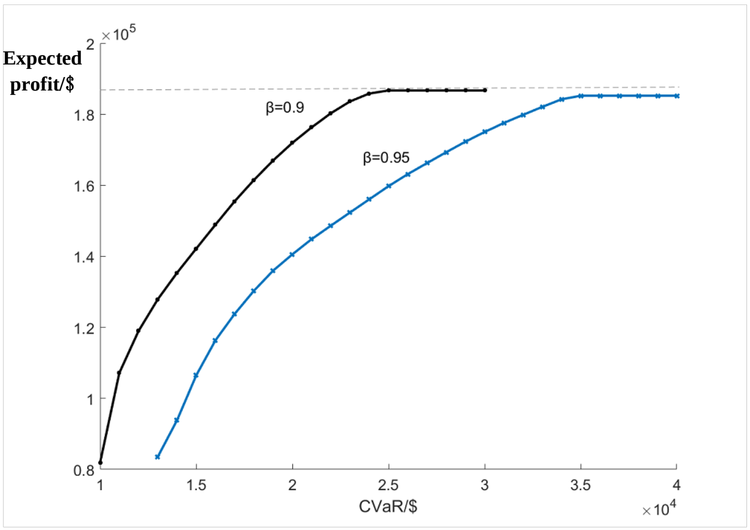

Figure 5. Effective frontier of expected profit and CVaR.

The effective frontier curve of expected profit and CVaR shown in Figure 5. It can be seen from the figure that the effective frontier curves at different confidence levels β show an increasing trend and reach the limit value (1.87×105$). This is because with the infinite increase of ω, the sellers will purchase electricity from the spot market without counting the risk loss, and CVaR will tend to be infinite. This illustrates the high-risk, high-income market investment principle, and the electricity sellers need to consider the risks and benefits comprehensively when purchase electricity.

G. *Risk Assessment of Stage 2*

Considering the ambiguous risk factors of investment incremental distribution network, including policy risk PR, natural disaster risk NDR and investment cost IC, this paper calculates the net cash flow increment within the investment period. The fuzzy membership function of the net cash flow increment can be calculated by the algorithm of fuzzy triangle.

After the construction of an incremental distribution network, the probability distribution of the quantity of electricity sales in the *n*-th year can be approximated as a normal distribution, and the profit of electricity sales also obeys the normal distribution. The investment period is 20 years, and the discount rate is 6.83%. According to expert predictions, the attribute values of policy risk, natural disaster risk and investment cost are given by triangular fuzzy numbers, as shown in Table 3.

Table 3. Fuzzy membership functions of risks.

PR(%/year)	NDR (million/year)	IC (billion $)
(4.5,6,7)	(1.6,2,2.3)	(0.37,0.5,0.67)

According to the optimal value of the expected profit calculated in the first stage, the profit of electricity sales in the investment period is estimated. The risk preference coefficient χ is introduced, expressed as $\chi=c\text{-}k\bullet\beta$, where c is a constant, and k is a positive proportional coefficient. In the example, c and k are both taken to ensure that the value is between 0 and 1. The membership function of the incremental cash flow under different risk preferences is shown in Figure 6.

In order to maximize the incremental cash flow of investment, the principle of maximum membership degree is adopted for investment decision. It can be seen from Figure 6 that with χ increasing, the image of the membership function of the incremental cash flow shifts to the right. If the expected profit of electricity distributors and retailers is below $0.2billion, the χ=0.4 investment plan should be chosen according to the principle of maximum membership. If the expected profit of electricity distributors and retailers is above $0.3billion, the χ=0.8 investment plan should be chosen. In general, the risk aversion coefficient must be increase if electricity distributors and retailers want to get more expected incremental cash flow. The fuzzy membership function provides reference value for the consideration of risk preference in investment decision.

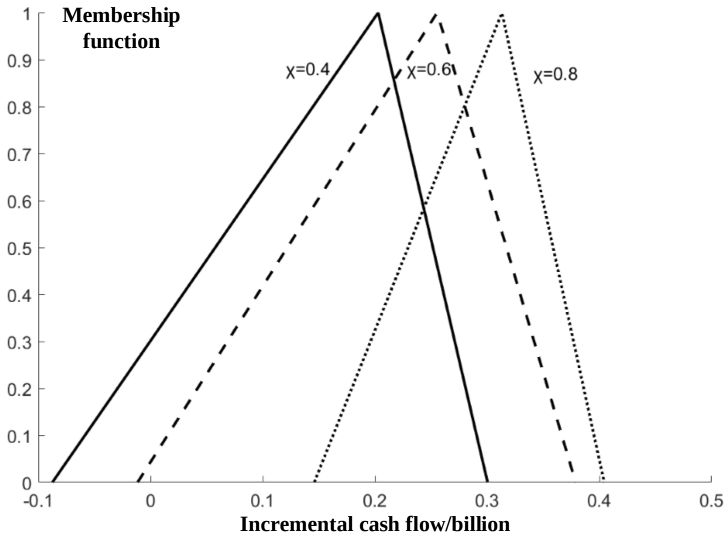

Figure 6. Membership functions of incremental cash flow under different risk preference.

5. Conclusion

This paper analyzes and summarizes the operational risks that may be faced by incremental electricity distributors and retailers. The fuzzy risk factors of investment projects, the risk of electricity purchase and sale, and the reliability of electricity supply were modeled respectively. Considering CVaR as the market risk measurement index, a two-stage risk optimization evaluation model was established.

After considering the demand response, the risk cost of the system electricity supply reliability is significantly reduced. The electricity distributors and retailers can choose a high-risk-high-yield or low-risk-low-yield investment strategy based on its own risk appetite. Different risk preferences will influence the decision of the investment plan, such as higher the expected incremental cash flow, the higher the risk aversion coefficient. Compared with the traditional model which only considering the price risk of electricity, this model has the advantages of comprehensive evaluation and sensitive analysis.

The model proposed in this paper provides a new method for the operation decision and risk assessment of the electricity distribution company. With the gradual promoting of electricity market reform, the risk control can be further explored in the future electricity market.

Acknowledgments

This work was financially supported by State Grid Anhui Electric Power Company Economic and Technical Research Institute Project “Research and Empirical Study on Distribution Network Planning Optimization Considering Opening Incremental Distribution Network”.

References

[1] R., D., L. Chen-Ching and L. J., Risk assessment in energy trading. IEEE Transactions on Power Systems, 2003. 18(2): p. 503-511.

[2] Xu, J., et al., Power Portfolio Optimization in De-regulated Electricity Markets with Risk Management. IEEE Transac-tions on Power Systems, 2006. 21(4): p. 1653-1662.

[3] Huang, J., et al., An Efficient Probabilistic Assessment Method for Electricity Market Risk Management. IEEE Transactions on Power Systems, 2012. 27(3): p. 1485-1493.

[4] LIU Weijia, SHANG Jincheng, ZHOU Wenwei, et al. Eval-uation of value-at-risk in electricity markets based on mul-tifractal theory[J]. Automation of Electric Power Systems, 2013,37(7):48-54.

[5] KANG Chongqing, ZHUANG Yan, HU Jiangyi, et al. Risk analysis on electricity sales in power sale market[J]. Pro-ceedings of the CSEE, 2009(19):78-84.

[6] XU Wei, XIA Qing, KANG Chongqing. Risk assessment of electricity buyers and sellers in power markets based on sequence operation theory[J]. Automation of Electric Power Systems, 2008(04):15-19.

[7] WANG Ren, SHANG Jincheng, ZHOU Xiaoyang, et al. Conditional value at risk-based optimization of power purchasing portfolio in multiple electricity markets and risk management[J]. Power System Technology, 2006(20):72-76.

[8] ZHANG Qin, WANG Xifan, WANG Jianxue. Electricity purchasing and selling risk decision for power supplier under real-time pricing[J]. Automation of Electric Power Systems, 2010(03):22-27.

[9] HUANG Hailun, YAN Zheng, YANG Yunyi, et al. Optimal strategy for distribution companies to purchase and sell electricity and manage risk considering consumers' price elasticity of demand[J]. Journal of Shanghai Jiaotong Uni-versity, 2012(07):1122-1126.

[10] ZOU Peng, LI Chunhui, GUO Jing, et al. Optimal market-ing strategy of distribution and retail companies con-sidering interruptible load[J]. Southern Power System Technology, 2017(02):71-77.

[11] LUO Qin, SONG Yiqun. Marketing strategy in competitive retail market considering interruptible load[J]. Automation of Electric Power Systems, 2015(17):134-139.

[12] Dicorato M, Forte G, Trovato M, et al. Risk-Constrained Profit Maximization in Day-Ahead Electricity Market[J]. IEEE Transactions on Power Systems, 2009,24(3):1107-1114.