Risk Assessment for Generation Investment by Random NPV Probit Model based on UNPV Method

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Abstract

Following the deregulation of the electric power industry, uncertainties such as volatilities in the demand and price of electric power and fuel have increased. It is therefore necessary to develop a new method to evaluate investment risks. We have previously developed a risk assessment method using utility indifference net present value (UNPV method). Though identifying the utility function used in the UNPV method is difficult, we propose a "probit" type statistical model to evaluate the investments. The model is derived from a simplification of the UNPV method, and is provided as a type of regression equation for the statistical moments of random net present value (RNPV). We compose a probit model for investment evaluation of a gas thermal power plant project, and compare the results of the UNPV method and the proposed probit model to examine the effectiveness of the proposed probit model.

Index Terms: expected utility theory, generation, investment evaluation, Monte Carlo method, natural gas, power system economics, probit model, random net present value, risk, utility indifference pricing

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1. INTRODUCTION

Recently, deregulation and reform in the electric power industry have progressed in many parts of the world. This new framework has resulted in the introduction of competition to the electric power generation and retail sectors, as well as open access to electric power networks. Pre deregulation, minimization of total costs was the primary objective when investing in generators. However, post deregulation, profit maximization, especially considering future uncertainties, has become increasingly important. In order to react to these future uncertainties and market risks in a competitive environment, an effective method to determine required investment levels in generation assets needs to be developed. The revenue from generation assets must be estimated properly on the basis of long-term forecasts of both demand and market price, as well as investors' attitudes toward expected risks.

Discounted Cash Flow (DCF) method is a well-known approach to assess project value[1]. Net Present Value (NPV) used in DCF method, however, has a limitation in that "random complexities" of cash flow caused by various future uncertainties are not sufficiently accounted for; hence, this approach does not provide investors with a suitable evaluation of a project's risks.

To overcome this limitation, a project assessment method based on "utility indifference pricing" of the expected utility theory has been proposed. This is called the utility indifference net present value (UNPV) method[2]. The UNPV method employs a utility function to evaluate investor attitude toward risk. The utility function presents investors' degree of satisfaction upon investing a unit of their property. We have previously applied the UNPV method to assess oil thermal generation projects[3]. However, because the utility function is not familiar to engineers, it is difficult to identify the utility function's parameters.

To avoid using the utility function, we have proposed a "probit model"[4] derived from a simplification of UNPV methods[5,6]. The model is outlined as follows: when we pay attention only to the investment's execution, the project can be expressed by a binary variable, that is, execution or rejection. The probit model is given as a type of regression equation in which dependent variable and explanatory valuables are a project's binary variable and several order moments of "random net present values (RNPV)." We estimate the model by assessing gas thermal power plant projects considering only fuel and electricity price uncertainty[5]. Price uncertainty is simply represented by the mean reverting model with probabilistic variables. We obtain good results from a second-order probit model, using av-

erage and variance of RNPV as explanatory variables.

This paper investigates the effectiveness of our probit model approach under more realistic price models. To make the uncertainty price models more realistic, we consider "price spikes." To sufficiently evaluate a project's execution, we extend the second-order probit model to a fourth-order model. By comparing the statistical results of these two probit models, we investigate the new probit model's effectiveness.

2. UNPV METHOD

2.1 Net Present Value Method

It is assumed that the time series of future cash flows $X = \{X_n, -1, 2, \cdots, N\}$ is obtained from the project annually. Let RPV be a random present value obtained from one trial, which is defined as (1).

$$RPV(X) = \left\{ \sum_{n=1}^{N} (X_n/(1+r)^n) \right\} \tag{1}$$

where N is the designated year and r is the discount rate. The present value PV is given by the expectation of RPV. That is,

$$PV(X) = E[RPV(X)] \tag{2}$$

where $E[\cdot]$ denotes the expectation. Thus, within the framework of the ordinary NPV method, the randomness of PV is treated only as the mean value. I represents the generation unit's construction cost, that is, the capital investment, the NPV is calculated by (3).

$$NPV(X) = PV(X) - I \tag{3}$$

In the conventional NPV, a project is executed if $NPV > 0$.

Remark 2.1:

Miyahara[7] has shown that UNPV corresponds to a "risk sensitive measure," therefore satisfying some suitable and reasonable characters as an evaluation tool for uncertain projects. The measure is called a risk sensitive value measure (RSVM). Recently, some fundamental studies and applications on RSVM have been proposed[14-17].

2.2 Utility Indifference Net Present Value Method[2]

In the framework of expected utility theory, uncertain return R can be evaluated by (4).

$$E[u(-v+R)] = u(0) = 0 \tag{4}$$

where $u(x)$ is the utility function with $u(0) = 0$. Utility function $u(x)$ presents investors' degree of satisfaction when they invest their property x. The value of return R as the "utility indifference price" is defined by the value of v. This means that the expected return equals 0 if investors pay the value of v for the right to obtain uncertain return R; in this context, R and v are balanced.

As most investors of electricity generation assets seek to avoid risk, $u(x)$ is assumed to be a risk-aversion type expressed by (5).

$$u(x) = (1 - \exp(-\beta x))/\beta \tag{5}$$

where β is a positive constant. On the contrary, when the utility function is given by $u(x) = x$, it is a risk-neutral type.

To evaluate the project's uncertain return, which is given as the difference between RPV and construction cost I, we substitute $RNPV(X) = RPV(X) - I$ for R in (4) and obtain (6).

$$E[u(-v+RNPV(X))] = 0 \tag{6}$$

The value of v satisfying (6) is referred to as the UNPV. In our framework, a project is executed if $v > 0$ instead of $NPV > 0$. Note that if $u(x) = x$, that is, the risk-neutral type, UNPV v coincides with NPV.

3 RNPV PROBIT MODEL

To calculate UNPV, that is, to calculate the expected value using (6), we employ a Monte Carlo method and obtain sufficient $RNPV$.

Using sufficient $RNPV$, we calculate average $E[RNPV]$ and variance $V(RNPV)$. Moreover, we determine the outcome—execution or rejection—by UNPV v. Then, UNPV v is transformed to a binary variable $\hat{v}$ as follows:

$$\begin{aligned} &\text{if } v > 0, \text{ then } \hat{v} = 1, \\ &\text{if } v \leq 0, \text{ then } \hat{v} = 0. \end{aligned} \tag{7}$$

$\hat{v}$ represents the project's execution or rejection. Thus, a set of variables $\{\hat{v}, E[RNPV], V(RNPV)\}$ is obtained. Note that on changing the simulation's conditions, we obtain other sets of these variables. Moreover,[6] derives a regression equation simplifying UNPV, which is estimated by using many sample sets. $\hat{v}$ is the dependent variable, while the average E $[RNPV]$ and variance V($RNPV$) are explanatory variables. That is,

$$\hat{v} = \hat{\beta}_0 + \hat{\beta}_1 E[RNPV] + \hat{\beta}_2 V(RNPV) \tag{8}$$

where $\hat{\beta}_0, \hat{\beta}_1, \hat{\beta}_2$ are regression coefficients obtained by the maximum likelihood estimation under the assumption that the estimation error in (8) is a Gaussian distribution. The model in (8) is called the second-order RNPV probit model. To assess the project, the average value and the variance of $RNPV$ are substituted in (8). If $\hat{v} > 0$, the project is executed.

When a distribution of $RNPV$ is a Gaussian distribution, (6) can be mathematically converted to (8) without the interception term $\hat{\beta}_0$. However, the resulting distributions of $RNPV$ are not Gaussian distributions because of price spike in fuel and electricity prices. To derive a more accurate probit model, a higher-order term should be employed. We use the third- and fourth-order central moments of $RNPV$. That is,

$$\begin{aligned}\hat{v} = &\hat{\beta}_0 + \hat{\beta}_1 E[RNPV] + \hat{\beta}_2 V(RNPV) \\ &+ \hat{\beta}_3 E[(RNPV - E[RNPV])^3] \\ &+ \hat{\beta}_4 E[(RNPV - E[RNPV])^4]\end{aligned} \tag{9}$$

The model in (9) is called the fourth-order RNPV probit model.

If the distribution of the estimation error in (8) or (9) is of the logistic type, we can obtain the second or fourth order RNPV "logit" model[6].

4 SIMULATION MODEL

4.1 Expression of Prices

This section applies the UNPV method and simplified RNPV probit model toward the investment in a gas thermal power plant.

Under a deregulated regime, the electric power industry poses significant risks. However, to simplify our simulation, we consider only wholesale electricity and natural gas price fluctuations in the market. We ignore other uncertainties, such as trading volume, bidding strategy, and transmission congestion. We consider only the cost of fuel to generate electricity, ignoring start-up costs.

Annual profit X for the time series of cash flow $\{N_n, n = 1, 2, \cdots, N\}$ is given by (10).

$$X = \left\{ \sum_{i=1}^{365} (14 \cdot (EP_i - H^* \cdot FP_i)) \right\} - OMC \tag{10}$$

where EP_i and FP_i are the daily average prices of electricity and natural gas on day i, respectively. H^* is the conversion rate, which will be explained in the next section. To simplify the simulation, it is assumed that the generator operates for 14 hours a day. Accordingly,

$X_i = 14(EP_i - H^* \cdot FP_i)$ is the cash flow per day. Annual profit X is the difference between the total profit of one year and the operating maintenance cost OMC as shown in (10).

The daily average prices of electricity and natural gas, EP_i and FP_i, respectively, are assumed to be described by the mean reverting models fluctuated by random numbers according to the Gaussian distribution[8].

$$EP_i = EP_{i-1}\exp\{[\alpha_1(\mu_1 - x_{1,\,i-1}) - \sigma_1^2/2]\Delta t + \sigma_1\sqrt{\Delta t}\,\varepsilon_{1,\,i}\} \tag{11}$$

$$EP_i = EP_{i-1}\exp\{[\alpha_2(\mu_2 - x_{2,\,i-1}) - \sigma_2^2/2]\Delta t + \sigma_2\sqrt{\Delta t}\,\varepsilon_{2,\,i}\} \tag{12}$$

where, α, σ, and Δt are mean regressive rate, volatility, and time interval, respectively, and ε_i is a series of normal random numbers. The constant μ is defined as $\mu = \ln(\overline{S})$, where $\overline{S}$ is the long-term price level. Subscripts 1 and 2 of σ and ε_i in (11) and (12) denote the parameters concerning the price of electricity and natural gas, respectively. We assume the random numbers of electricity and gas prices, $\varepsilon_{1,\,i}$ and $\varepsilon_{2,\,i}$, respectively, as being statistically independent.

When we consider price spike, the prices obtained by (11) or (12) is multiplied by price spike magnification m_s according to the price spike probability p_s.

4.2 Simulation Method and Parameters

Using appropriate values of long-term price level $\overline{S}$, mean regressive rate α, and volatility σ, we employ a Monte Carlo method to attain many $RNPV$ values. We run 20,000 trials for cases without price spikes, and 50,000 trials for cases with price spikes using the Monte Carlo method. UNPV v is then calculated using (6) and converted to the binary variable $\widehat{v}$ as mentioned in Sec. III. Thus, we can obtain one set of variables $\{\widehat{v}, E[RNPV], V(RNPV)\}$.

Changing parameters $\overline{S}$, α, and σ, we repeatedly run the Monte Carlo method to obtain many sets of variables $\{\widehat{v}, E[RNPV], V(RNPV)\}$. From these sets, we obtain the probit model as mentioned in Sec. III.

All parameters except $\overline{S}$, α, and σ used in the simulation are listed in Table I.

TABLE I SIMULATION PARAMETERS

Δt [year]	1/365	r	0.03
N [year]	22	I [JPY/kW]	$2.0^* 10^5$
OMC [JPY/(kW · year)]			9636

The conversion rate H^* is defined as follows: the calorific value of natural gas is approximately 1 MMBtu $= 252 \times 10^3$ kcal. Assuming a generating efficiency of 43% and an exchange rate of 1 USD $= 100$ JPY, we can calculate H^* [(JPY/MMBtu)/(USD/kWh)] using 1 kWh $= 860$kcal.

$$H^* = \frac{860}{252 \times 10^3 \times 0.43} \times 100 = 0.79 \tag{13}$$

5 RESULTS OF UNPV

5.1 Cases without Price Spike

The electricity price parameters $\bar{S}$, α, and σ are based on the system price data of JEPX[9]. Natural gas price parameters are based on the price of Hunny Hub[10].

Table II shows a section of the UNPV simulation results considering uncertainty only in natural gas prices without the price spike. Concerning the other parameters except for those listed in Tables I and II, volatility σ of natural gas price is set at 1.0. Parameters $\bar{S}$ [JPY/kWh], α, and σ of electricity price are set at 9.5, 110 and 3.3, respectively.

TABLE II UNPV WHEN $\bar{s}$ AND α OF
GAS PRICE ARE CHANGED

$\bar{S}$ \ α	5	10	15	20	40
6.2	−114 44	6868	1332 4	1670 4	1942 3
6.3	−207 16	1446	7452	9663	1292 7
6.4	−278 57	−848 1	−874	3066	6517

On the right side surrounding bold lines in Table II, the project is evaluated to determine if it should be executed under these conditions, as UNPV is positive. On the contrary, the project should not be executed in the conditions given on the left side.

We calculated 47 and 60 cases considering uncertainties in electricity prices and natural gas prices, respectively. In addition, 255 cases were simulated considering uncertainties in both electricity and natural gas prices. Thus, we calculated 362 cases in total. The parameters $\bar{S}$, α, and σ for electricity prices fluctuated in the range of 9.0–10.3, 70–160, and 2.5–39,

respectively. The parameters $\overline{S}$, α, and σ for natural gas price fluctuated in the range of 5.7–6.5, 5–40, and 0.5–2.0, respectively. Based on JEPX and Hunny Hub prices, these value ranges selected as the UNPV results are split into positive or negative, that is, project execution or rejection.

5.2　Cases with Price Spike

Cases of price spikes for electricity and/or natural gas are considered. A price spike is generated at constant probability p_s with no relation to time series. During a price spike, the average price during the entire day is assumed to jump by a certain constant magnification m_s.

Table III shows a segment of the UNPV simulation results considering uncertainty only in natural gas prices with the price spike. Natural gas price volatility σ is set at 1.0, and the parameters of price spike m_s and p_s are set at 2 and 0.1% , respectively. Moreover, in Table II, parameters $\overline{S}$[JPY/kWh], α, and σ of electricity price are set at 9.5, 110 and 3.3, respectively.

TABLE Ⅲ　UNPV WHEN $\overline{S}$ AND α OF GAS PRICE ARE CHANGED WITH PRICE SPIKES

$\overline{S}$ ＼ α	10	15	20	25	30
6.0	717	11800	19624	23597	25684
6.2	−13599	−2153	6031	10563	12354

UNPV here is lower than the results shown in Table II as the natural gas price, that is, the fuel price, is higher than the cases in Table II due to the price spike.

We simulated 240 cases with price spikes in electricity and/or natural gas prices. The price parameters $\overline{S}$, α, and σ of electricity and natural gas fluctuated, as in the previous section. Concerning price spike parameters, probability p_s and magnification m_s fluctuated in the range of 0.1%–5% and 2–10, respectively.

6 RESULTS OF RNPV PROBIT MODEL

6.1 Cases without Price Spikes

Using the results from the 362 cases in Sec. V-A, the second-order RNPV probit model (8) is derived. The obtained RNPV probit model with interception is shown in (14), while (15) shows the model without interception.

$$\hat{v} = -2.124 + 4.29 \times 10^{-4} E[RNPV] - 1.21 \times 10^{-7} V(RNPV)$$
$$(-4.641)\ (6.622) \qquad\qquad (-6.480) \qquad\qquad\qquad (14)$$

$$\hat{v} = 2.458 \times 10^{-4} E[RNPV] - 8.81 \times 10^{-8} V(RNPV)$$
$$(7.987) \qquad\qquad (-7.702) \qquad\qquad\qquad (15)$$

The t-ratio values are shown in parentheses under each regression coefficient.

The fourth-order RNPV probit model shown in (9) is also derived. The obtained probit model is shown in (16) and (17). The t-ratios for (16) and (17) are listed in Table IV.

$$\hat{v} = -1.694 + 5.220 \times 10^{-4} E[RNPV] - 1.766 \times 10^{-7} V(RNPV)$$
$$-9.484 \times 10^{-12} E[(RNPV - E[RNPV])^3]$$
$$+3.153 \times 10^{-17} E[(RNPV - E[RNPV])^4] \qquad\qquad (16)$$

$$\hat{v} = 3.824 \times 10^{-4} E[RNPV] - 1.481 \times 10^{-7} V(RNPV)$$
$$-1.388 \times 10^{-11} E[(RNPV - E[RNPV])^3]$$
$$+1.142 \times 10^{-17} E[(RNPV - E[RNPV])^4] \qquad\qquad (17)$$

Table IV shows the comparison between the second-order and fourth-order RNPV probit models. From top to bottom, it shows the number of incorrect results of the RNPV probit model from UNPV results, the proportion R/N which adheres to both results, the t-ratio for regression coefficients of interception, average E[$RNPV$], variance V($RNPV$), third- and fourth-order terms, and Wald test statistics.

TABLE IV   RESULTS OF RNPV PROBIT
MODEL (WITHOUT PRICE SPIKES)

interception	second-order model		fourth-order model	
	With	with out	with	with out
Fault	14	24	13	18
R/N	96.1%	93.4%	96.4%	95.0%

	−4.6 41		−3.8 43	
	6.62 2	7.98 7	6.22 8	6.76 7
t-ratio	−6.4 80	−7.7 02	−5.8 32	−6.4 89
			−0.6 76	−1.0 59
			0.74 9	0.29 8
Wald	44.2 5	63.8 3	39.6 3	46.5 8

The assessment of whether to execute or reject a project on the basis of the proposed probit model is almost the same as results based on the UNPV method. As described above, identifying the parameters of the utility function is difficult. However, this result indicates that the utility function is not necessary if sufficient information from the results of project assessment is available. Using these results, we can determine the RNPV probit model and assess the project by the probit model.

T-ratio absolute values, with the exception of the higher-order terms determined in Table IV, are larger than 2.59, which is the value of 1 percentage point of the t-distribution. Moreover, the Wald test values are larger than 9.21, which is the value of 1 percentage point of the x^2 distribution. Therefore, we conclude that all explanatory variables except those for higher-order terms are significant. Higher-order terms, however, are not significant, indicating that the regression equation does not require these higher-order terms as explanatory variables. That is, the second-order RNPV probit model is sufficient for cases without price spikes.

Finally, as previously mentioned, the interception is not theoretically required when an *RNPV* distribution is a Gaussian distribution[6]. However, the difference between *RNPV* and Gaussian distributions requires the intercept to suppress the error.

6.2 Cases with Price Spikes

Using the results from 240 cases from Sec. V-*B*, the second-order RNPV probit model shown in (8) is derived. The obtained probit model with interception is shown in (18), while that without interception is shown in (19).

$$\hat{v} = -0.728 + 3.21 \times 10^{-4} E[RNPV] - 1.20 \times 10^{-7} V(RNPV)$$
$$(-1.948)(6.264) \qquad\qquad (-5.791) \qquad\qquad\qquad (18)$$

$$\hat{v} = 2.91 \times 10^{-4} E[RNPV] - 1.20 \times 10^{-7} V(RNPV)$$
$$(6.458) \qquad\qquad (-6.316) \qquad\qquad\qquad (19)$$

The fourth-order RNPV probit model in (9) is derived. The obtained probit model is shown in (20) and (21), and t-ratios of (20) and (21) are listed in Table V.

$$\hat{v} = -0.761 + 9.197 \times 10^{-4} E[RNPV] - 4.410 \times 10^{-7} V(RNPV)$$
$$+ 7.237 \times 10^{-11} E[(RNPV - E[RNPV])^3]$$
$$+ 7.215 \times 10^{-16} E[(RNPV - E[RNPV])^4] \qquad\qquad (20)$$
$$\hat{v} = 8.623 \times 10^{-4} E[RNPV] - 4.330 \times 10^{-7} V(RNPV)$$
$$- 6.941 \times 10^{-11} E[(RNPV - E[RNPV])^3]$$
$$+ 6.956 \times 10^{-16} E[(RNPV - E[RNPV])^4] \qquad\qquad (21)$$

Table V shows the comparison between the second-order and fourth-order RNPV probit models. From top to bottom, Table V lists the number of incorrect results of the RNPV probit model from UNPV results, the proportion of R/N that adheres to both results, the t-ratio for the regression coefficients of interception, the average $E[RNPV]$, the variance $V(RNPV)$, the third- and fourth-order terms, and the Wald test statistic.

TABLE V RESULTS OF RNPV PROBIT
MODEL (WITH PRICE SPIKES)

	second-order model		fourth-order model	
interception	with	with out	With	with out
Fault	13	14	6	7
R/N	94.58%	94.17%	97.50%	97.08%
t-ratio	−1.948		−1.147	
	6.264	6.458	4.117	4.090
	−5.791	−6.316	−4.110	−4.092
			3.533	3.335
			3.870	3.725
Wald	39.33	41.70	17.34	17.85

The Wald test shows the significant explanatory variables, and the t-ratio, with the exception of the interception, shows the significant explanatory variables. Especially, the third- and fourth-order terms in the fourth-order RNPV probit model are significant, indicat-

ing that the regression equation requires these higher-order terms as explanatory variables.

The assessment of whether to execute or reject a project on the basis of the proposed probit model is almost the same as results based on the UNPV method as well as the cases without price spikes. The error of the fourth-order RNPV probit model from the UNPV is smaller than that of the second-order RNPV probit model. Therefore, the fourth-order RNPV probit model is effective for cases with price spikes.

Finally, the t-ratio of the interception is smaller than the value of 1 percentage point of the t-distribution. Though we think the interception term is used for the difference in the *RNPV* and Gaussian distributions, the price spike is thought to comprise much of a difference between the *RNPV* and Gaussian distributions. We hypothesize that the significance of interception becomes relatively lower because the higher-order term has larger significance. The exact resolution of this discrepancy will be addressed in our future work.

6.3 RNPV Probit Model by All Cases

Finally, using the results of all 602 cases ($=362$cases without price spikes$+240$cases with price spikes), the second-order RNPV probit model in (8) is derived. The obtained probit model with interception is given in (22), while that without interception is given in (23)

$$\hat{v} = -1.455 + 3.31 \times 10^{-4} E[RNPV] - 1.00 \times 10^{-8} V(RNPV)$$
$$(-5.328)\ (9.553) \qquad\qquad (-8.758) \tag{22}$$
$$\hat{v} = 2.37 \times 10^{-4} E[RNPV] - 8.99 \times 10^{-8} V(RNPV)$$
$$(10.64) \qquad\qquad (-10.27) \tag{23}$$

The fourth-order RNPV probit model in (9) is also derived. The obtained probit model is shown in (24) and (25), and t-ratios of (24) and (25) are listed in Table VI.

$$\hat{v} = -1.565 + 5.071 \times 10^{-4} E[RNPV] - 1.852 \times 10^{-7} V(RNPV)$$
$$+ 2.568 \times 10^{-11} E[(RNPV - E[RNPV])^3]$$
$$+ 1.331 \times 10^{-16} E[(RNPV - E[RNPV])^4] \tag{24}$$
$$\hat{v} = 3.733 \times 10^{-4} E[RNPV] - 1.586 \times 10^{-7} V(RNPV)$$
$$+ 1.933 \times 10^{-11} E[(RNPV - E[RNPV])^3]$$
$$+ 1.083 \times 10^{-16} E[(RNPV - E[RNPV])^4] \tag{25}$$

Table VI shows a comparison between the second-order and fourth-order RNPV probit models. From top to bottom, Table VI shows the number of incorrect results of the probit model from UNPV results, the proportion of R/N that adheres to both results, the t-ratio for the regression coefficients of interception, the average E[*RNPV*], the variance V(*RNPV*),

the third- and fourth-order terms, and the Wald test statistic, as well as Tables IV and V.

TABLE VI RESULTS OF RNPV PROBIT
MODEL (ALL 602 CASES)

	second-order model		fourth-order model	
interception	with	with out	with	with out
Fault	31	40	20	26
R/N	94.85%	93.36%	96.86%	95.68%
t-ratio	−5.328	/	−4.609	/
	9.553	10.64	8.195	8.982
	−8.758	−10.27	−8.041	−8.879
	/	/	4.479	4.157
	/	/	6.264	6.438
Wald	91.42	113.1	68.33	81.31

The Wald test and t-ratios show all explanatory variables to be significant. The error of the fourth-order RNPV probit model from the UNPV is smaller than the one in the second-order RNPV probit model shown in Table V. Therefore, the fourth-order RNPV probit model is effective in all cases, with or without price spikes.

7　CONCLUSION

We had previously proposed a risk assessment method for generation investment with various uncertainties by using a probit model described by the moments of RNPV. On having sufficient information regarding a project's assessment results, that is, execution or rejection, as well as the average and variance of the NPV, the probit model as a regression equation can be determined. In this paper, we apply the probit model to assess a gas thermal power plant project. We investigate the effectiveness of the proposed probit model under more realistic price models. Though uncertainties only in electricity and natural gas prices are assumed, we calculate 362 cases without price spikes and 240 cases with price spikes under different conditions. From the results of these cases, we derive the RNPV probit model and compare it with the results from the UNPV method which is the origin of our

statistical model. Moreover, we prepare two probit models, a second-order RNPV probit model, in which explanatory variables include the average and variance of *RNPV*, and a fourth-order RNPV probit model, in which explanatory variables include the average, variance, and the third- and fourth-order central moments. According to our results, the probit model is mostly consistent with the UNPV method for risk-averse investors. If project assessment data does not include price spikes, the second-order RNPV probit model is sufficient. However, if the data includes price spikes, the use of the fourth-order RNPV probit model is required, as proposed in this paper, to represent the difference between the RNPV and Gaussian distributions.

These results indicate that risk-averse investors can directly apply our probit model to practical project evaluations without using the UNPV method. The procedure for such an evaluation is outlined as follows:

(a) The investor prepares ahead of time the assessment results for execution or rejection together with the RNPV moments obtained by simulation data using various scenarios.

(b) Using the results, the second- or fourth-order RNPV probit model is derived from the maximum likelihood estimation.

(c) On the basis of another scenario simulation, the investor obtains sample RNPV values for the new project under evaluation, and calculates the moments of RNPV for the project.

(d) Finally, the investor substitutes the moments from (c) into the RNPV probit model obtained in (b), and determines execution or rejection of the new project based on the model's signature.

The probit model theory can be developed in various forms[4], and we have already proposed an extension of the model to a three-level ordered probit model[11], and an application to assessment of a project's execution probability[12,13]. We can easily extend these results to the case of logit model. On the other hand, we must actually show our method's applicability an application to a practical problem.

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