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Evaluation of Renewable Energy Project by Risk Sensitive Value Measure Method

Hajime Miyauchi*, Daigo Yoshimoto, Takahiro Koga***, Harumi Izutsu****, Tetsuya Misawa*******

**Faculty of Advanced Science and Technology, Kumamoto University, Kumamoto, Japan (Tel: +81-96 342 3612; e-mail: miyauchi@cs.kumamoto-u.ac.jp).*
*** Graduate School of Science and Technology, Kumamoto University, Kumamoto, Japan (e-mail: d_yoshimoto@st.cs.kumamoto-u.ac.jp)*
**** Graduate School of Science and Technology, Kumamoto University, Kumamoto, Japan (e-mail: t_koga@st.cs.kumamoto-u.ac.jp)*
***** Graduate School of Science and Technology, Kumamoto University, Kumamoto, Japan (e-mail: h_izutsu@st.cs.kumamoto-u.ac.jp)*
****** Graduate School of Economy, Nagoya City University, Nagoya, Japan, (e-mail: misawa@econ.nagoya-cu.ac.jp)*

Abstract: Due to the uncertainty of electric power price and output of renewable energies, investors for renewable energies are facing large risks. To estimate the project, Net Present value (NPV) is well employed, however, NPV cannot evaluate risk correctly because it evaluates only the expected value of future cash flow. We have proposed a new evaluation method using Risk Sensitive Value Measure (RSVM) and it is applied to thermal power plant project. In this paper, we present the evaluation of the renewable energy project by RSVM. By using RSVM, the optimum and the maximum investment for renewable energy project is obtained.

Keywords: Renewable energy systems, Project selection, Risk, Net present value, Probability distribution, Risk sensitive value measure, Expected utility theory

1. INTRODUCTION

Under the deregulation of the electric power utilities, electric power companies compete each other to acquire customers and the electric power price is settled in the electric power market. As the uncertainty such as electric power price, fuel price and demand, are increasing, the return of the investment for electric power assets also becomes much more uncertain. Therefore, as it is difficult for investors to decide project execution, they seek an appropriate evaluation method for the asset investment.

As the evaluation method of power plant investment, NPV (Net Present Value) method is well known and commonly used (Clewlow, 2000). However, because NPV method only evaluates the expected value of the future cash flow by discounting it to the present value, it cannot evaluate correctly the risk of project. Furthermore, it can consider neither flexibility nor attitude of investors towards the project risk. To address the uncertainty in future, real option is employed generally (Hedman, 2005) (Martinez-Cesena, 2011). Real option is a "risk hedge" strategy against the uncertainty in projects.

On the other hand, to evaluate the investment of projects including risks, there is an approach based on the expected utility theory called "Utility indifference Net Present Value method (UNPV method)" (Miyahara, 2006). We have already presented the evaluation of power plant investment project applying UNPV method. We have also evaluated the projects of thermal power plants including real option by UNPV (Miyauchi, 2007). Furthermore, paying attention to the fact that the optimal investment scale and the maximum allowable scale are obtained by considering the investment scale in the UNPV method, the risk aversion parameter appearing in the utility function can be estimated from the correspondence with the actual photovoltaic power generation project (Ide, 2014).

RSVM (Risk-Sensitive Value Measure) is formulated in the framework of UNPV when the exponential function is adopted as the utility function in UNPV. RSVM provides an evaluation conformable to expected utility, which implies that the evaluation by the RSVM is desirable and proper (Miyahara, 2010) (Ban, 2016) (Hodoshima, 2020). RSVM is the method to evaluate assets, cash flows, projects, and so on with uncertain outcomes.

We note that the difference between RSVM and "Value at Risk (VaR)", which is the popular risk assessment measure of probabilistic distribution (Miyahara, 2010) (Hodoshima, 2020). VaR evaluates the down side risk of the probabilistic distribution of project uncertainty. On the other hand, RSVM evaluates the whole probabilistic distribution.

RSVM method can discuss the scale of investment, and also using this property, we can estimate the optimal capacity allocation of each power generation. That is, it can define the portfolio in the generation project (Furukawa, 2017).

In this paper, we apply RSVM method to evaluate wind turbine generator projects, one of renewable energy generation systems. First, we compare the evaluation method with Mean Variance (MV) approach. MV approach is one of the typical risk and value evaluation methods that have been studied in risk management theory and project evaluation theory. This approach evaluates the risk of project as variance of distribution of NPV. Comparing with MV approach, we make clear the characteristics of RSVM method. Next, we investigate the relationship between scale of wind turbine generator and the average wind velocity. Thus, we make clear the effectiveness of RSVM method together with the characteristics of wind turbine generator projects.

This paper contains five sections. In Section 2, evaluation methods of projects are explained. In the end of this chapter, we explain RSVM method. In Section 3, we describe the comparison between MV approach and RSVM method by using photovoltaic (PV) system project. In Section 4, we apply RSVM method to wind turbine generator (WTG) project to show the optimum capacity of WTG and the relationship between capacity of WTG and the average wind velocity. Finally, we conclude in Section 5.

2. EVALUATION METHOD OF PROJECT

2.1 Random Net Present Value

We first define random net present value (*RNPV*). It is assumed that the time series of cash flow $X=\{X_n, n=1,2,\cdots, N\}$ is obtained from the project every year in future. Considering uncertainty of cash flow, we may regard X as a stochastic process. *RNPV* is defined as (1).

$$RNPV(X) = \left\{\sum_{n=1}^{N} \frac{X_n}{(1+r)^n}\right\} - I \qquad (1)$$

where, N is the designated year and r is a risk-free rate. I represents the construction cost of the project. Net Present Value *NPV* is given by the expectation of many ***RNPVs*** given by many trials.

$$NPV(X) = E[RNPV(X)] \qquad (2)$$

where, $E[\cdot]$ denotes the expectation. According to Net Present Value method, it is decided to execute the project when $NPV>0$.

2.2 Mean-Variance Approach

Mean-Variance (MV) approach is the evaluation method using mean value and variance of the random NPV (RNPV). In this approach, the portfolio of projects is evaluated by (4) when RNPV for the portfolio of projects is defined as P expressed by (3).

$$P(X^1, X^2, \cdots, X^J) = \sum_{j=1}^{J} \lambda_j\, RNPV(X^j) \qquad (3)$$

$$MV(\beta, P) = E[P] - \frac{\beta}{2} Var[P] \qquad (4)$$

where, X^j is cash flow of jth project, λ_j is scale of jth project, β is risk-aversion and $Var[\cdot]$ denotes the variance of *RNPV*. As mentioned, this approach is one of the typical risk and value evaluation methods for determining optimal asset allocation. However, this approach has some problems as followings.

- Positive bias of RNPV distribution is evaluated negatively as well as negative bias.
- Default loss is hardly reflected in evaluation.
- MV approach is based on the convenience that Gaussian distribution can be expressed by mean value and variance. However, RNPV distribution is not always similar to Gaussian distribution.

Due to these properties, MV approach is not well suited for the evaluation of capital investment.

2.3 Risk Sensitive Measurement Value Method

Risk Sensitive Measurement Value (RSVM) method is based on Utility indifference Net Present Value (UNPV) method. Therefore, UNPV method is mentioned first.

In the framework of the expected utility theory, the uncertain return *RNPV* is evaluated by (5).

$$E[u(-\nu + RNPV(X))] = 0 \qquad (5)$$

where, $u(x)$ is the utility function with $u(0)=0$. The utility function $u(x)$ presents the satisfaction degree of investors when they invest their property x. As most investors in electrical power industries seek to avoid their risk, the utility function $u(x)$ is assumed to be expressed by (6).

$$u(x) = \frac{1}{\beta}(1 - \exp(-\beta x)), \qquad \beta > 0 \qquad (6)$$

where, β is a positive constant. Equation (6) presents the utility function of risk aversion type. On the contrary, if the utility function is given as $u(x)=x$, it presents the risk neutral type.

The value of *RNPV* as "utility indifference price" is defined by the value of v. It means that the expected return is equal to 0 if the value v is paid for the right to obtain the uncertain return *RNPV*, and in this context, *RNPV* and v are balanced. We call v as "utility indifference net present value (UNPV)". When UNPV $v>0$, the project should be executed.

Risk-Sensitive Value Measure (RSVM) method is UNPV method when the exponential function shown by (6) is adopted as the utility function. RSVM is given by (7)

$$RSVM(\beta, P) = -\frac{1}{\beta}\ln(E[\exp(-\beta P)]) \qquad (7)$$

Note that $E[\exp(-\beta P)]$ corresponds to the generating function of P. Thus, RSVM evaluates the whole probabilistic distribution of P. When $RSVM>0$, the project should be executed. If RNPV distribution of the project has negative NPV values, we can obtain the optimal investment scale, the maximum allowable investment scale and the optimal asset allocation. RSVM has properties as followings.

- Positive bias of RNPV is evaluated positively.
- Default loss is acutely evaluated.

- The optimal investment scale, the maximum allowable investment scale and the optimal asset allocation can be obtained.

3. RSVM METHOD AND MV APPROACH

3.1 Model of Photovoltaic System

In this section, we evaluate photovoltaic (PV) project. PV is one of renewable energies and its capacity is rapidly increasing. In Japan, as feed-in tariff (FIT) was introduced in 2012, the capacity of PV was 9,110 MW at the end of 2012 Financial Year (FY) and increases rapidly up to 47,730 MW at the end of 2017 FY (METI, 2019).

The income of investors for PV is guaranteed under FIT to some extent. However, they face the uncertainty of output of PV because of the fluctuation of irradiation. Furthermore, it is possible to be curtailed the output of PV by the power system operator to secure the system stability recently. The latter makes also the income uncertain.

There are so many uncertainties in real system. RSVM method can evaluate the project with many uncertainties if it is properly modelled. However, we consider only irradiation and fault of PV as uncertainty in this study because our purpose is only to estimate the effectiveness of RSVM method in this paper.

From the real data of irradiation measured by Meteorological Agency in Japan, appearance frequency of hourly irradiation divided every 1 kWh/m^2 is counted for each month. We compose the probabilistic function of irradiation from the distribution of appearance frequency. Output of PV is calculated by irradiation decided by this probabilistic function.

We select three locations in Kyushu Island, Japan, that is, Miyazaki, Kumamoto and Fukuoka. As Miyazaki is located in the south part of Kyushu Island, it has much enough irradiation comparing to Fukuoka, which locates in the northern part in Kyushu Island. Kumamoto is middle point and middle irradiation between two other locations.

An occurrence of the fault in PV is judged every five year. The fault probability increases with the passage of years. When the fault occurs, PV requires an additional cost which includes the opportunity loss.

Table 1 shows the costs used in this simulation. These costs are evaluated by Ministry of Economy, Trade and Industry, Japan (METI, 2016).

Table 1. Cost estimation for PV

procurement period	20 years
procurement cost	30 JPY/kWh
operating and maintenance cost	8,000 JPY/(kW year)
capital cost	292,500 JPY/kW

3.2 Simulation Results Without Fault

First, we show the simulation results of project evaluation without fault. The distribution of RNPV is shown in Fig. 1. It looks like Gaussian distribution. The minimum RNPV is positive for Miyazaki. It means this project can always recover the investment and is successful. On the other hand, the minimum RNPV is negative for Kumamoto and Fukuoka.

The project of investment scale λ, that is, the capacity of PV is evaluated by MV approach and RSVM method. The evaluation results are shown in Fig. 2.

As the project does not make loss when the minimum RNPV is positive as the case in Miyazaki, the project should evaluate monotonous increase along with the scale. RSVM evaluates the project as monotonous increase along with the scale. However, the project value evaluated by MV approach is decreasing when the scale is larger. Because MV approach evaluates the variance as risk, the evaluation value by MV approach is decreasing when the scale becomes large. It is not reasonable for the property that the project in Miyazaki does not make any loss.

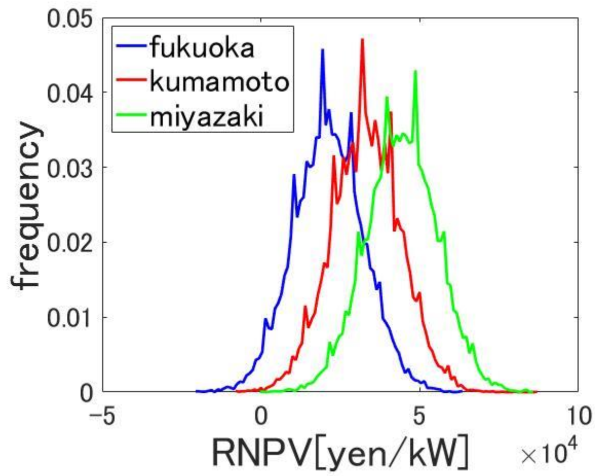

Fig. 1. Probabilistic distribution of RNPV (without fault)

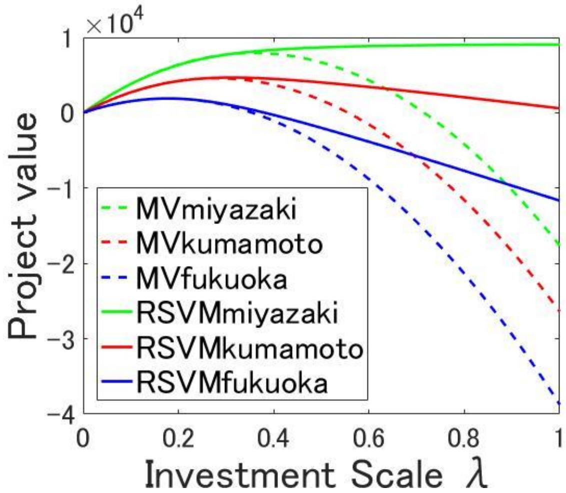

Fig. 2. Project evaluation results of MV approach and RSVM method (without fault)

3.3 Simulation Results With Fault

Next, we investigate the simulation results of project evaluation with fault. The distribution of RNPV is shown in Fig. 3. If the fault is considered, the distribution of RVPV shows a slightly different shape than Gaussian distribution. The minimum RNPV is negative also for Miyazaki when considering the fault probability in PV.

The project of investment scale λ, that is, the capacity of PV is evaluated by MV approach and RSVM method. The evaluation results for the case considering the PV fault are shown in Fig. 4. As MV approach regards the distribution of RNPV as Gaussian distribution, the estimation of variance is not correct. Nevertheless, MV approach cannot evaluate correctly as it evaluates using an incorrect variance. On the other hand, because RSVM method evaluates RNPV distribution by applying the utility function as the risk of investors, it can evaluate such a non-Gaussian distribution correctly.

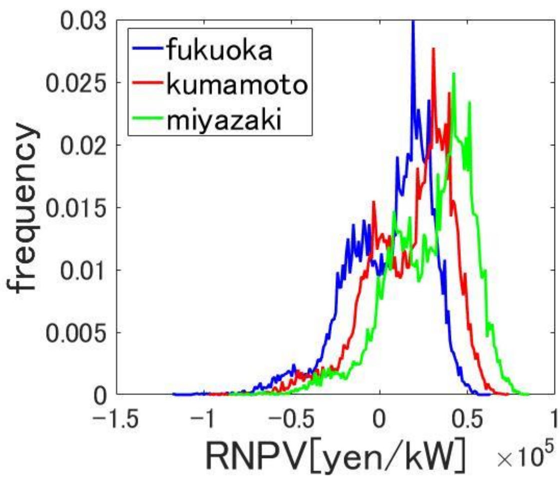

Fig. 3. Probabilistic distribution of RNPV (with fault)

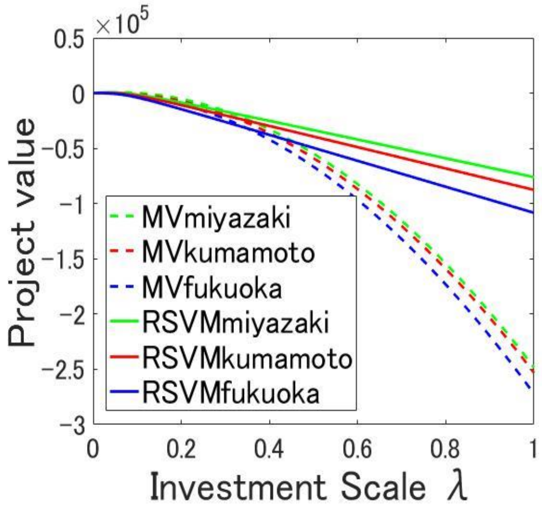

Fig. 4. Project evaluation results of MV approach and RSVM method (with fault)

4. OPTIMUM SCALE ESTIMATION BY RSVM METHOD

4.1 Model of Wind Turbine Generator

RSVM method can estimate the optimum scale and the maximum scale of the investments. We indicate it using the project evaluation of wind turbine generator (WTG) in this section.

First, we mention about the model of WTG. WTG model used in this simulation has 80m diameter windmill. Its capacity is 2MW. The cut-in, rated and cut-out wind speed is 3m/s, 12m/s and 25m/s, respectively.

Table 2. Cost estimation for WTG

procurement period	20 years
procurement cost	21 JPY/kWh
operating and maintenance cost	6,000 JPY/(kW year)
capital cost	300,000 JPY/kW

Table 2 shows the costs used in this simulation. These costs are evaluated by Ministry of Economy, Trade and Industry, Japan (Enecho, 2016).

As we want to make clear that RSVM can evaluate the optimum scale and the maximum scale of the project, we make the problem simple in this study as well as Section 3. The income of investors for PV is guaranteed under FIT as well as PV. We only consider wind velocity and fault of WTG as uncertainty in this study. Wind velocity is expressed using the Weibull distribution based on the daily average wind speed of each site in 2014. The fault probability of WTG is 10 %/year. If the fault occurs, the duration of the fault is fixed according to Table 3. In the fault, the income of WTG is reduced the same amount as (annual NPV average)× (suspension period).

The different location of WTG project is compared by RSVM. We select seven locations of which the yearly average wind velocity (JMA, 2020) is relatively high in Japan as listed in Table 4.

Table 3. Failure probability of WTG

case	Low	LM	Mid	HM	Heavy
ratio (%)	20	25	20	20	15
duration (days)	3	7	14	30	90

Table 4. WTG location and average wind velocity

location	ave. wind v	location	ave. wind v
Soya	7.6	Okushiri	6.2
Muroto	6.9	Okinoerabu	6.0
Shimochi	6.8	Miyakejima	5.8
Yonaguni	6.3		(m/s)

4.2 Simulation Results

We calculate RNPV distribution of one WTG for each location through 20,000 trials. Figure 5 shows the project evaluation results by RSVM method. As some RNPV are negative for all locations, curves of RSVM are convex upward. At the maximum point for investment scale λ on the convex curve, an investor is fully satisfied. Then, it is the optimum point to invest. The maximum allowable investment scale is at the point where RSVM curve crosses zero value again.

Table 5 summarizes the optimum investment scale λ and the maximum allowable investment scale λ from Fig. 5. It is found that the maximum RSVM at the optimum investment scale λ is higher when the average wind velocity is higher. However, the results for Okushiri and Yonaguni are slightly different. Though the average wind velocity in Okushiri is lower than the one in Yonaguni, the maximum RSVM at the optimum scale λ and the maximum allowable investment scale λ of Okushiri are larger than ones of Yonaguni. Similarly, the maximum RSVM at the optimum scale λ for Muroto is lower than Shimochi. They are indicated by a gray colored column in Table 6.

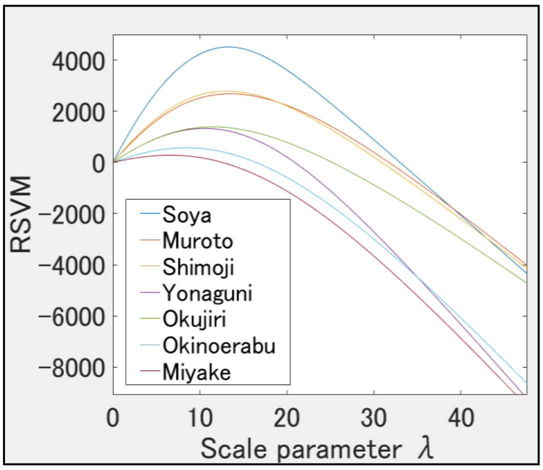

Fig. 5. Project evaluation results of WTG

Table 6. Summary of project evaluation of WTG

location	ave. wind v	Optimum λ	max RSVM	Maximum λ
Soya	7.6	14	4513	34
Muroto	6.9	14	2682	32
Shimochi	6.8	14	2790	31
Yonaguni	6.3	12	1327	21
Okushiri	6.2	12	1392	26
Okinoerabu	6.0	9	573	17
Miyakejima	5.8	8	282	13

Table 7. Comparison of output energy

wind v(m/s)	Okushiri		Yonagumi	
	days	output	days	output
3.0-6.9	135	5.5MWh	209	8.5MWh
7.0-11.9	85	67.0	109	84.4
12.0-	46	92.0	16	32.0
total	266	164.5	334	124.9

To investigate the reason, we compare the daily average wind velocity and the yearly total output energy from WTG for each band of wind velocity at Okushiri and Yonaguni. The comparison of frequency and output energy of each wind velocity band are listed Table 7. At Okushiri, the daily average wind velocity is less than 3m/s, that is, cut-in wind velocity, for about 100 days. It means WTG cannot output electricity for about 100 days. The number of days less than 3m/s is larger than Yonaguni. Nevertheless, Okushiri is evaluated higher by RSVM comparing with Yonaguni because the frequency of the daily average wind over 12m/s, that is the rated wind velocity, is larger. Therefore, WTG is evaluated highly when it can generate over the rated wind velocity as much as possible. Thus, RSVM evaluates the whole probabilistic distribution.

As the parameter β in the utility function (6) influences these results, it is important to fix β for the project evaluation by RSVM. To apply RSVM to the project evaluation, we consider estimation methods of β, such as the evaluation of historical data and the survey of investor opinion. Otherwise, the method to avoid the use of the parameter β is also considered. This is our future task.

5. CONCLUSIONS

In this paper, we apply RSVM method to evaluate the project of renewable energies. RSVM is based on expected utility theory and can be considered the attitude of investors for the risk. RSVM can indicate the optimum investment scale, the maximum allowable investment scale and the optimal asset allocation.

First, we compare RSVM method with conventional MV approach to evaluate PV projects. When the project does not produce any loss even in any conditions, the project should be evaluated to execute always for any scale. Though RSVM method evaluates like the above, MV approach evaluates negative for large scale. Because MV approach evaluates variance as a risk, the positive side variance is evaluated as a risk.

Next, we apply RSVM method to evaluate WTG project. From the results, to success the project, it is necessary to consider the distribution of wind velocity, especially over the rated wind velocity of WTG, not only the average wind velocity.

Thus, we make clear the effectiveness of the new project evaluation method RSVM. It is necessary to develop an estimation method of the parameter in the utility function. Furthermore, we must apply RSVM method to more detail model with much more uncertainty risks. These are our future issues. We continue to investigate on RSVM to make clear the characteristics of evaluation by RSVM.

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