Economic Evaluation and Scenario Analysis of Wind Generations Based on Environment Factors

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Abstract: - This paper presents a wind plant economic evaluation and scenario analysis approach by taking environment factors into consideration. In order to install large-scale wind generators to power systems, active power *controls* by complimentary fossil fuel power generators are indispensable under the cooperation with power companies for maintaining system frequency. The new evaluation model of CO2 emission of thermal generators is proposed to regulate output fluctuations of wind generators. Scenario analysis is undertaken to verify the proposed approach for evaluating economical and environmental impacts of wind plans**.** By applications of the proposed approach to a test power system, it has bee proved that the complimentary supplies by oil-fired thermal power generators against the output power change of wind power generators make CO_2 emission decrease by 25-30% compared with that of conventional wind generators.

Key-Words: - Wind Plant, application general balance model, amount of CO_2 emission

1 Introduction

For environmental preservation and exhaustion of fossil fuels, effective use of renewal energy is attracting world-wide interest. At COP-3 in Japan, December 1997, Kyoto Protocol was adopted by countries. The objective of the Protocol is to reduce the amount of the greenhouse effect gases (CO2, CH4, CO, HFCs, PFCs, and SF6) by 6 % compared with that in 1990 from 2008 to 2012[2]. To cope with the international-adoption, Japanese government has set up a long-range prospect of energy supply and demand to introduce wind turbine generators up to “300 million kW in 2010” and to give financial assistances to attain the target. On the occasion of introducing wind turbine generators, influences of system interconnections of them are alarmed. Although effective countermeasures that reduce the influence with introducing NAS batteries are proposed, the benefit against cost is discussed due to the increase of construction cost. In order to introduce large-scale wind generators, active power controls by fossil fuel power generators are indispensable under the cooperation with power companies for maintaining system frequency. The Carbon tax has already been carried in the part of European countries and is also anticipated to be introduced on CO2 emission from now on. in Japan

Therefore, economic evaluations of wind generations with consideration of environment and system interconnection factors become important issues. This paper proposes an economic evaluation model and methodology of wind generations by taking environment and system interconnection factors into account and verifies the appropriateness of the proposed method by simulations.The obtained result by the proposed wind generation economic evaluation would supply precious information for working out strategies by government and energy–related companies.

2 Economic Evaluation of Wind Generations

2.1 Features of Wind Power Generation

As advantages of wind power generations, those are clean power generation systems, because it has no emissions such as, CO2, radioactive waste, that cause the pollution of the environment compared with thermal power generation and nuclear power generation. Also, wind generations are renewal energy and inexhaustible. However, as the direction and velocity of wind, which is the motive force of wind power generations, are changed continuously, output from the systems is unstable. As energy density of wind is low and unstable, the use rate of facilities is generally low (average 20 %).

To compensate these short points of wind power generations, some countermeasures should be adopted for the wide spread of wind power generations Different countermeasures have to be chosen for different types of wind generations, such as "independence type", which are not interconnected to the grid, "small type" which are installed on the roof of buildings, and "large wind generator", which are connected with the grid.

1) For independence type and small type, power storages are used to make output power smooth.
2) Large wind generators, which are a part of power systems, are interconnected with the grid to supply their output to the systems continuously. Therefore, to realize this continuous and stable power supply, wind power generators are combined with conventional generations, e.g., oil-fired thermal power generators to complement the fluctuation of wind power outputs.

Wind power generations have no emission of CO2. However, it is pointed out that when unstable output power of wind power generations are complemented and regulated by oil-fired thermal power generators, the total CO2 emission from the combined supply doesn't always decrease rather increase on the contrary. This shows that in performing the economic evaluation of wind generations, a comprehensive evaluation is needed to evaluate not only profits by wind generators but also benefits for whole power generation system which supplies consumers with stable power.

In this paper, we discuss a wind plant economic evaluation regarding "large-scale and grid-interconnected wind generations" (from now on it is named "large wind generators) To attain this purpose, a new wind plant economic evaluation method is proposed to analyze installation and operation cost of system interconnection devices, and evaluate social economic benefits which is brought by CO2 emission reduction/increase by combining wind generators and oil-fired thermal power generators as the complementary supply.

2.2 Factor of Generation System Cost and Wind Generation Economic Evaluation

(a) Economic evaluation of conventional power generation system

Generally, economic values of power generation systems are evaluated by power generation costs. Power generation cost is calculated as an annual cost divided by an annual amount of output power. An annual cost is composed of fluctuation costs, such as fixed cost and operation maintenance cost, the fixed cost is calculated by the capital recall method. In the capital recall method, the fixed cost is represented as multiplication of the construction cost and the annual expenditure rate. The power generation cost is calculated by next equation

The power generation cost (yen/kWh)

= (Construction cost ×an annual expense rate + operation maintenance cost)/ an annual amount of output power

$$\text{Annual expense rate} = \frac{r}{1-(1+r)^{-n}}$$

r- Interest rate

n- Lifetime

(b)Evaluation by NPV

NPV（Net Present Value）is represented as the sum that present value that future cash flow. is a standard method in finance of capital budgeting – the planning of long-term investments. Using the NPV method a potential investment project should be undertaken if the present value of all cash inflows minus the present value of all cash outflows (which equals the net present value) is greater than zero. By using NPV, we can measure and evaluate all items by a common standard as the cash flow, and carry out the scenario and sensitivity analysis on different situations against variations of conditions, so we can evaluate projects (PV) from multiple viewpoints.

NPV=(present cash flow value from PJ)

$$= \sum_{i=1}^{n} \frac{CF_i}{(1+r)^i} - \text{(Present investment value for PJ)}$$

CF_i: Cash flow in year-i

r : Interest rate

(c) Consideration factor of wind plant economic evaluation

As wind power generations have no emission of contamination and those are clean power generations, in the economic evaluation, the following factors must be taken into consideration.

1) As wind power generations operate at about 20% efficiency on the average and change their output power from 0% to 100%, it is necessary to use some other power generations to make output stable. Judging from present power system operation, the power generations, which can make outputs of wind power generations, stable extensively and efficiently are oil-fired thermal power generators and pumped-storage power stations. In case of the combination of "wind

generators and oil-fired thermal power generators", to keep stable power supply to consumers, "oil-fired thermal power generators" which are connected with the grid must complement output fluctuations of wind power generations. So, in discussing the economic evaluation with large and interconnected wind generations, correlations with other complementary generators, which can make output, stable should be incorporated into the evaluation analysis too.

2) In case of the combination of "wind generators and oil-fired thermal generators complement", CO2 emissions from oil-fired thermal power generators as the complementary generators vary according to the change of wind speed. Especially in case of introducing the carbon tax in the future, the effect of CO2 emission by realizing planned wind firm national projects and the economic impacts due to the introduction of the carbon tax on CO2 emission cannot be ignored. Also, the economic analysis and evaluation for wind plants and CO2 emission by econometric models are essential.

3) Large wind generators, which are connected with system interconnection equipments, protection devices and maintenance costs for the system interconnection. Generally, those are capitalized into the investment of wind firm projects is general. Fig.2 indicates cash flow of large wind generator. For introducing large wind generators, total project costs (including construction costs and land costs) and system interconnection costs have to be added up as the initial cost. As the cash flow income from wind plants, we obtain the sum of an annual profit for wind plants and system maintenance costs including interconnection and protection devices. Fig.3 indicates CO2 emissions between the grid and wind power generations. By introducing wind plants, variation of CO2 emissions is finally affected by the operating pattern of "wind power generators and complementary oil-fired thermal power generators". Generally speaking, if output power of wind power generators is stable, oil-fired thermal power generators playing the role of complementary generators do not need any adjustment against unstable output of wind power generators. So, CO2 reductions only from wind generators are expected and those produce environmental and economic benefits for the power system too.

On the other hand, if output of wind power generators is unstable to large extent, oil-fired thermal power generators are need to be adjusted and the CO2 reduction is not large enough what is expected. What is worse, the possibility of CO2 increase cannot be denied. Environmental and economic effects due to introduction of wind plants are very different. Therefore, the effect of CO2 emission depending on the stability of output power from wind power generators should be evaluated by some appropriate methods. The problem and its formulations are described in the next section.

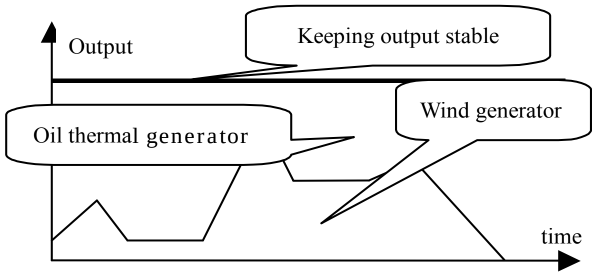

Fig.1 Combinatorial operation of wind and oil thermal generations

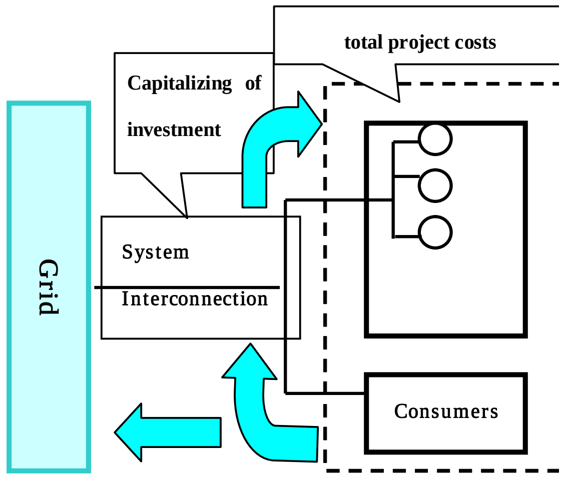

Fig.2 Cash flow of large wind generator

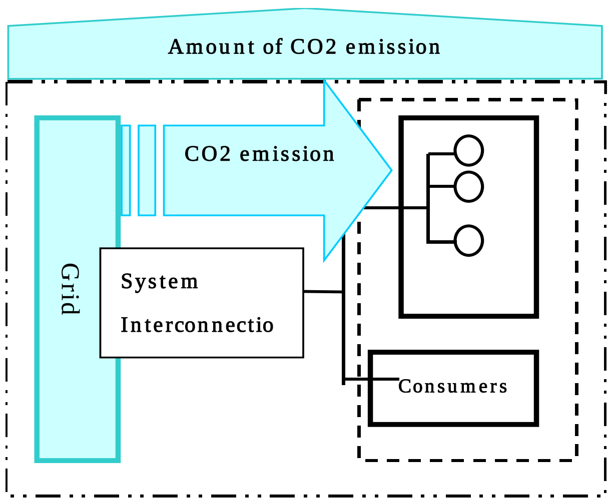

Fig.3 CO2 emission from grid and wind generators

3 Selections of environment and system interconnection factors

3.1 Capitalization of carbon tax by application general balance model

CO2 tax (Carbon tax) that levies a tax depending on the amount of CO2 emission is so called the environmental tax introduced in European countries such as Finland and Holland. In Japan, Environmental Agency is discussing the introduction of the carbon tax and making various researches related to effects and consequences of the carbon tax. In particular, many quantity models to evaluate the reduction of CO2 emission quantitatively as the measure of global warming are developed. As output power of wind power generators can decrease CO2 emission, it is essential to evaluate quantitative economic effects due to CO2 emission related to wind power generators. AIM/Material model is a model that can evaluate quantitatively the effect of the reduction of environmental burdens on economic activity by using the general equilibrium model incorporating the environmental burdens caused by economic activities. Especially as this model includes a module to evaluate the amount of CO2 emission, it becomes possible to calculate carbon tax prices under the macroscopic views [3]. Under those backgrounds, in this paper, we adopted 15,587 yen/tC carbon tax calculated by AIM/Material model to reduce the amount of CO_2 emission by 2% compared with the year of 1990 [3].

3.2 Calculation of CO2 emission due to unstable output of wind power generators

3.2.1 Weibull distribution of wind

Using the Weibull distribution can approximate occurrence probability distribution of wind.

$$f(V) = \frac{k}{c}\left(\frac{V}{c}\right)^{k-1} \exp\left\{-\left(\frac{V}{c}\right)^{k}\right\} \qquad (1)$$

f(v)- Appearance probability of wind-V
c- Criterion coefficient
f- Form coefficient

Also the average wind velocity is calculated by the following expression.

$$\overline{V} = c\Gamma\left(1+\frac{1}{k}\right) \qquad (2)$$

Γ is represented as the Gamma function $\Gamma(\lambda) = \int_0^{\infty} x^{\lambda-1} e^{-x} dx$

Fig.4 indicates an example of Weibull distribution curve. In the Weibull distribution, as the value of the form coefficient-k increases, the peak is being acute and the criterion coefficient-c is wind-V when cumulative probability of wind-V becomes 63.2%. In Japan, k is about from 0.8 to 2.2, as an annual average wind velocity increases, it increases too. If an annual average wind velocity is more than 5 m/s, k is from 1.5 to 2.2.

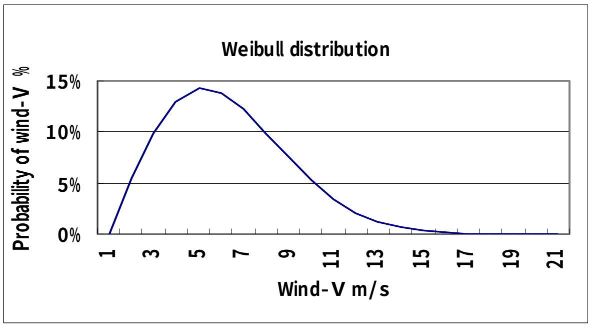

Fig.4 Example of weibull distribution curve

3.2.2 Introduce of Wind Power Change Coefficient by Weibull Distribution.

To represent output power changes of wind power generators, wind power change coefficient- ξ is defined as the following expression by Weibull distribution of wind.

$$\xi = \int_0^{V_{\max}} \frac{\left|\overline{P} - P(V)\right|}{P_{\max} - \overline{P}} dV \qquad (3)$$

$\overline{P}$ is average output power of wind power generator. This value of wind power change coefficient- ξ is from 0 to 1. $\xi = 0$ is when output power of wind power generators (wind velocity) is stable. $\xi = 1$ is when output power of wind power generators is very unstable.

3.2.3 Reduction of CO2

As mentioned previously, when the power system compensates output power change of wind power generators, usable power generations would be oil-fired thermal power generators within thermal power generations, but due to the use of fossil fuel, CO2 emission is to increase and them it must be accounted as CO2 increase by wind power generators. Addition to it, as the amount of CO2 emission by oil-fired thermal power generators is larger than other generators, the possibility for increase of total amount of CO2 emissions by introducing wind generators cannot be denied. Following expressions indicate the reduction of CO2 when output power of oil-fired thermal power generators is used as the complementary supply against the. fluctuations of wind powers.

$$E_{CO2} = P_{Total} \times C_{thermal} - I_{CO2} \quad (4)$$

$$I_{CO2} = \varsigma \times Q_{short} \times (CO2_{thermal} - CO2_{oil}) \quad (5)$$

E_{CO2} ：Reduction of CO2

ICO2 ：Increase of CO2

Qshort ：Shortage fluctuation amount

CO2：CO2 emission coefficient (g C / kWh)

Thermal ：Thermal power average

Oil ：Oil-fired thermal power average

When wind power change coefficient-ξ is 0, CO2 increase is 0 due to no effect on grid. Reduction of CO2 is the amount of output power by wind generators.

Table 1 Coefficient of CO2 emission of each generator

Thermal Power Generation	Coal-fired	242
	Oil-fired	192
	LNG-fired	130
	Average	164
All Power Generation		101

4 Application Results and Scenario Analysis

4.1 Calculation Method

This paper evaluates the economic impacts of wind plants by using "a wide–use software of wind plant economic evaluation" (supplied by New Energy Foundation) by taking consideration of the following factors. This software evaluates economic impacts using the capital collection method by NPV noted at chapter 2. However, to realize the proposal of this paper, we put the following assumptions.

1) In calculation of expenditure rate, "a modified unit price of electricity" by taking CO2 emissions into account is used as a unit price of electricity.
Modified unit price of electricity
=Unit price of electricity ±CO2 emission unit price
By introducing wind generations, when the total CO2 emission in the grid decreases, the unit price of CO2 emissions is positive (+). When the total CO2 emission in the grid increases, the unit price of CO2 emissions becomes negative (－).

2) As a part of equipment investments, the cost for system interconnections is counted as a fixed cost (mainly, land cost).

3) The part of equipment investment for system interconnections is counted as an operation maintenance cost.

4.2 Scenarios Considering Each Factor

By using the proposed model, economic impacts regarding "large and system-interconnected wind power generations" under environmental and system interconnection factors are evaluated.

Case1 Standard model (Standstill scenario)
In the standard model, ten of 80kW generators are introduced and construction cost is 180,000 yen/kW and the unit price of electricity is assumed as 9 yen/kW.

Case2 Introduction of the carbon tax
Based on CO2 reduction brought by execution of the carbon tax, the cash flow is calculated.

Case3 Capitalizing of investment for system interconnection.

On the assumption of interconnection of fuel cells, the cash flow is calculated. In this case, ζ is 0 because fuel cells can make output power stable.

4.3 Application Results under Scenarios

The results from case1 to case3 are indicated following.

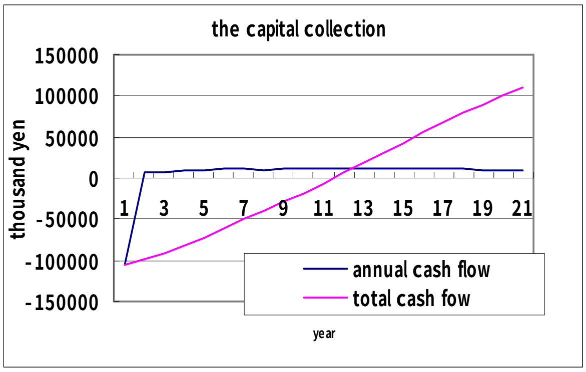

Fig.5 Cash flow in case 1

Table 2 the rate of operation and CO2 emission quantity

Region	Hokkaido Komamae	Aomori Rokkasyo	Chiba Cyoushi	Isikawa Nanao
k	2.1	1.8	2.2	1.9
c	7.3	7.7	7.0	5.8
use rate of facilities	25%	29%	23%	15%
Eco2(t/year) Ico2=0	335.2	392.7	308.4	202.5
ξ	0.302	0.386	0.255	0.175
Eco2(t/year)	244.9	284.8	217.8	143.5
Region	Kyouto Ine	Tottori Oyama	Kouchi Muroto	Saga Karatsu
k	1.8	2.0	2.2	2.1
c	4.5	6.3	7.9	7.9
use rate of facilities	8%	18%	30%	30%
Eco2(t/year) Ico2=0	109.3	239.0	405.5	309.0
ξ	0.087	0.208	0.375	0.369
Eco2(t/year)	74.1	173.2	291.7	293.0

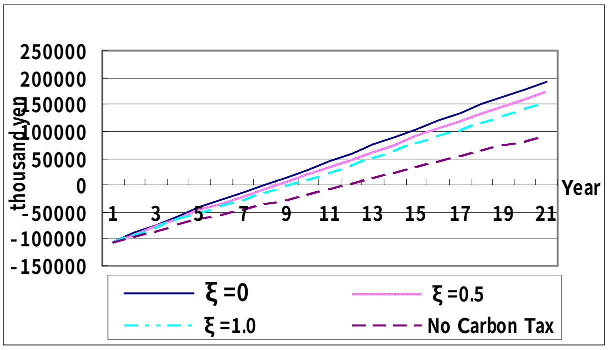

Fig.6 Cash flow in case 2

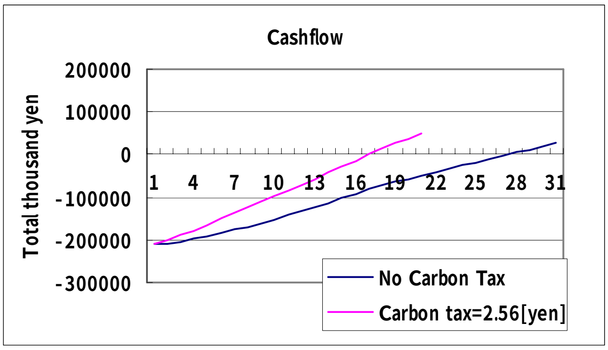

Fig.7 Case flow in case 3

4.4 Result Analyses

Case1 indicates the obtained cash flow in standstill scenario and shows that investment return is realized 12 years later and the profit increases after the year.

In case 2, coefficients of wind power variations and reduction of CO2 are calculated by the form and criterion coefficient in each region. Because of the output power change of wind power generators, complimentary supplies by oil-fired thermal power generators make CO2 emission decrease by 25-30% compared with that of conventional wind generator. In the model with the carbon tax, if wind power change co coefficient is 0, investment recall is realized 10 years later.

In case 3 with system interconnection, though investment recall is 15 years-delay compared with Case1, with carbon tax and wind power change coefficient = 0 investment recall is realized 16 years later.

By the proposed model, we can evaluate environmental and economic impacts from the viewpoint of not only power output of wind power generators but also the reduction of CO2 under output power changes.

5 Conclusion

In this research, an economic evaluation model and an analytical approach of wind generations are proposed by taking the consideration of environment and system interconnection factors and verified the practicability and effectiveness of the method by simulations on a test power system. In the conducted applications on the model system in this paper, interconnections and power supply of wind generators do not always make CO2 emission increase but it has been shown that in a specific region with low efficiency, there is such possibility of CO2 emission increase. It has been approved that in interconnecting wind generators to the grid, more precise evaluation based on realistic date concerning wind generations characteristics and fluctuations of wind powers are indispensable.

References:

[1] R. Yokoyama, "Liberalization of Electricity Markets and Technological Issues", Tokyo Denki University Press, 2001.

[2] "Kyoto Protocol to the United Nations Framework Convention on Climate Change" [Online]. Available: http://www.unfccc.int, 1992

[3] T Masui, "Development of Applied General Equilibrium Model Integrated Environment and Economy",

[4] Howe, H.:"Development of Extended Linear Expenditure System from Simple Saving Assumptions, European Economic Review, Vol.6", pp.305-310, 1975

[5] EIA Energy Glossary, Energy Information Administration. (2004) [Online]. Available: http://www.u.eia.doe.gov.