A Study of Optimal Capacity of BESS to Mitigate Unstable of Solar Power Generation

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Abstract—**Sustainable energy resources such as solar energy are in the spotlight to achieve post-carbon-society. However, the vast space is required to install PV generators compared with other distributed generators. The optimal usage of PV generator has to be investigated if it is installed in the limited areas. On the other hand, the output of PV power generator is not constant and varies depending on climate conditions. It causes difficulty in the power system operation and control when introduced into distributed networks or demand side. BESS (battery energy storage system) attracts attention as the device which is able to mitigate the change of PV generation output.**

As the first step in this paper, the relation between the solar radiation on PV and typical installation parameters such as azimuth and tilt angle of PV array is investigated as the usage of PV generators. In the second step, the combination of PV generation system and BESS is discussed from the viewpoint of cost and CO2-emission when installed on demand side, and the optimal installation capacities of PV generators and BESS are calculated.

Keywords-CO2-emission; PV generation; Tilt angel; BESS; Optimal capacity; Demand side; Reverse power flow;

I. INTRODUCTION

Sustainable energy resources such as solar/wind power generation are used increasingly in order to reduce CO2-emission. In the U.S., the concept of smart grid including renewable energy has been demonstrated in the New Energy for America (Green New Deal). The Japanese government has decided that the total installation capacity of solar power generation would be 53GW by 2030. However, a vast space is needed to introduce PV generation because a solar energy has lower density and lower generation efficiency. Therefore, the efficient usage of PV generation in limited area is required.

Furthermore, the photovoltaic generation is unstable due to the change of insolation and has the problem to cause difficulty in power system operation and control when introduced into distributed networks or demand side. As the countermeasure for these concerns, BESS (battery energy storage system) attracts worldwide attention. Also in the concept of smart grid, BESS plays important roles to keep the demand/supply balance and power quality.

The major roles of installing them are listed below;

- Load frequency control.
- Time shift by charging at the off-peak-time and discharging at the load-peak-time. This is called 'Load Leveling'.
- A backup generation
- Absorption of the surplus power which is generated from renewable energy such as a solar power generation.
- Spinning reserve
- Regulation
- Congestion easing of a power transmission line

Although BESSs are usually installed in the utility side for the load leveling, they have been introduced on demand side in recent years. This is because the maximum receiving-power (peak demand) has a major impact on the cost incentives. Therefore, the maximum receiving-power should be suppressed throughout a year. In addition, the economical benefit is obtained to store the inexpensive energy at the night-time. The discussing subjects in this paper are listed below;

(1)Optimal installing condition of PV panels

This is investigated to use PV generation efficiently. The parameters of the installing condition for PV generation are tilt angle and azimuth. This is studied based on the characteristics of photovoltaic generation obtained from METPV-3[1].

(2)Optimal installation capacities of PV generator and BESS

Due to the output of PV generation systems is not constant and varies depending on climate conditions, the combination of PV generation system and BESS is necessary for the stable operation. These are calculated from the viewpoint of cost and CO2-emission.

II. FUNDAMENTAL CHARACTERISTIC OF PV GENERATION

In this chapter, the characteristics of solar radiation are discussed with the data of solar radiation obtained by New Energy and Industrial Technology Development Organization (NEDO), Japan [1].

A. *Monthly characteristics of solar radiation*

Fig.1 and Fig.2 show the relations between the monthly amount of solar radiation and the tilt angle of PV panels.

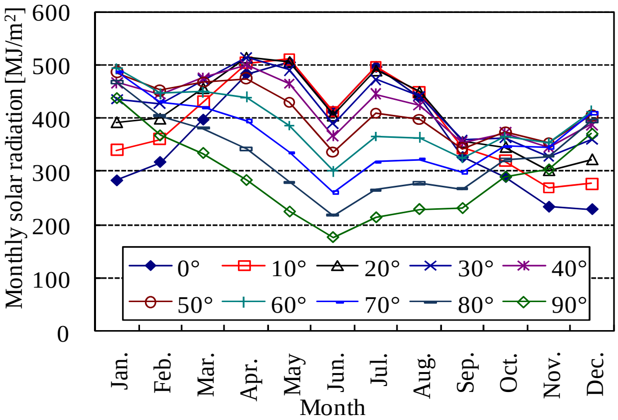

Fig.1 Monthly characteristics of solar radiation depending on the tilt angle in the South

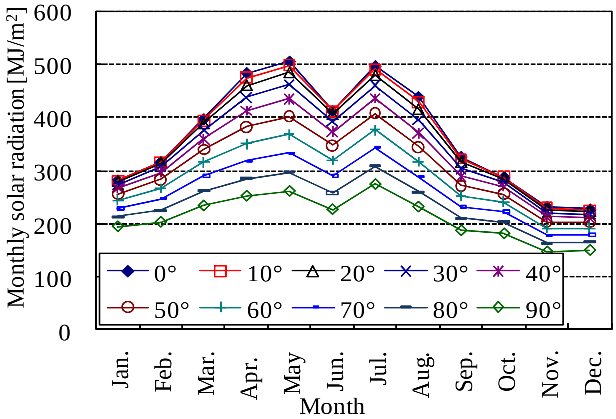

Fig.2 Monthly characteristics of solar radiation depending on the tilt angle in the East and West

The amount of solar radiation in the south varies according to the season. This is because the altitude of sun changes at each season and the received amount of solar radiation with PV panels changes. Monthly solar radiations at the direction of southeast and southwest are the same characteristic as in the south. The solar radiation tends to decrease toward summer if the tilt angle of PV panels is narrower.

On the other hand, the characteristics of solar radiation in the east and west are the same at the tilt angle. The amount of solar radiation decreases if the tilt angle is narrower. The solar radiation in June is less than May and July because it is rainy season in Japan.

As the results of above discussed monthly characteristics, the followings are obtained.

(i) At the direction of south, the large amount of solar radiation can be obtained by changing the angle of PV panels in each month.

(ii) The larger solar radiation is obtained by installed PV panels with wider tilt angle in the east and west.

B. *Annual characteristics of solar radiation*

The maximum solar radiation in a year and the annual amount of solar radiation, are shown in Fig.3 and Fig.4, where these are normalized with maximum value. The largest maximum solar radiation in the year is obtained by installing PV panels with the angle of 50° to south. On the other hand, the largest amount of solar radiation can be obtained with the angle of 30° southwardly. As a result, southward with the tilt angle of 30-50° is efficient to receive the more solar radiation annually.

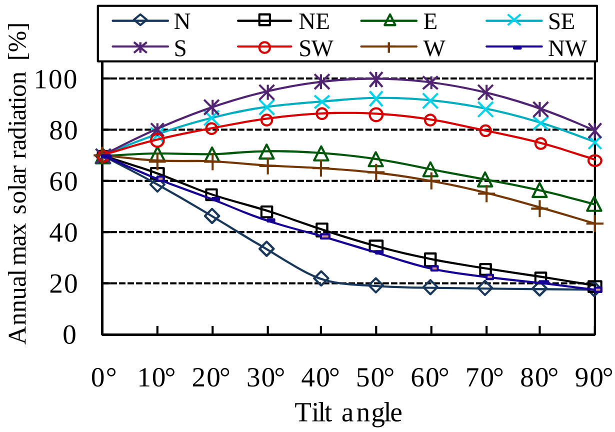

Fig.3 The maximum solar radiation in a year [W/W]

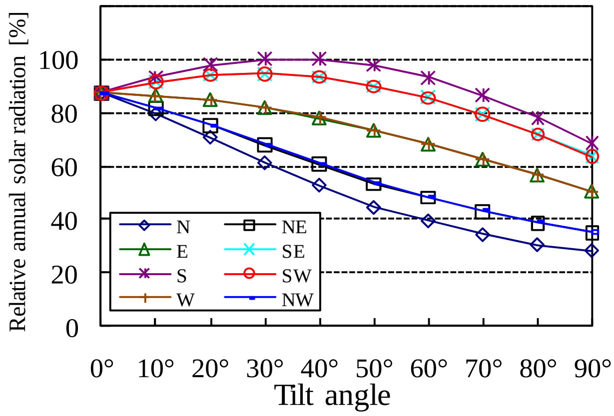

Fig.4 The annual amount of solar radiation [Wh/Wh]

III. Simulation for Optimal Capacities of PV and BESS

The PV generation is unstable due to the change of insolation and has the problem to cause difficulty in power system operation and control when introduced into demand side. As the countermeasure for these concerns, BESS has installed widely. Therefore, combination of PV generation system and BESS is necessary for economy and environment. In this chapter, the optimal capacities of PV generation and BESS are calculated in demand side by considering the cost and CO2-emisiion. These calculations are simulated through a year based on the typical data of a factory in Japan.

A. The load curves in demand side

In this section, the demand load curves which used in the simulation are explained. The load curve in demand side for a week is shown in Fig.5. This load is typical load curve of factory in Japan. The shape of demand curves does not change much through Monday to Friday. Saturday's load is about 80% of weekday, and the load on holiday is lower than weekday through a year. In the simulation of this paper, the consecutive holidays such as the New Year holidays, the holiday week in May in Japan and the summer vacation are included.

The time of peak load in the day is 9:00-16:00 similar to the output of PV generation. The load is lower between 12:00 and 13:00 suddenly, because there is a lunch break at this time.

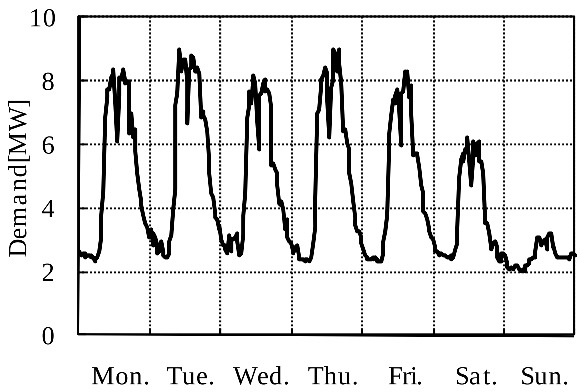

Fig.5 The load curve in demand side for a week

B. Output curves of PV generation systems

The output of PV generation system is not constant and varies depending on climate conditions. It is factor has to be considered in order to obtain the optimal capacity of BESS. Therefore, the output curves of PV generation at each day are selected at random from the recorded data of solar radiation in each month in Japan Meteorological Agency [6]. Fig.6 shows the solar radiation curves in January. These are normalized with the maximum value through a year.

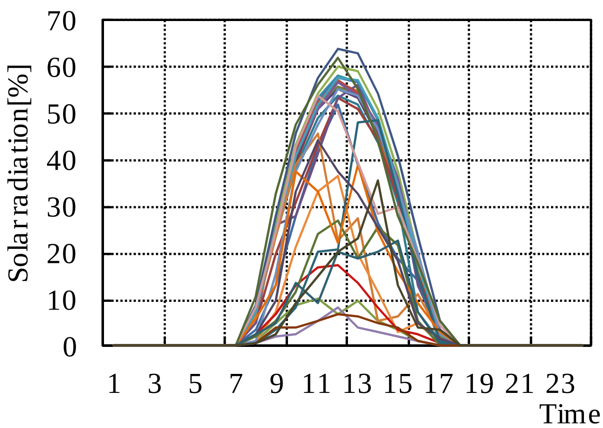

Fig.6 Curves of solar radiation in January (2009)

C. Operation control of BESS using the forecasting

BESS has to be operated through a day without the shortage and full charging of battery energy to control the output of PV generation. Therefore, in this section, the operation control of BESS is proposed using the load forecast curve and the PV power forecast curve. The operation control of BESS is outlined below;

(1)The load curve and PV generation power are forecasted by the day before the BESS operating. In this paper, the forecast curves are assumed that can be forecasted within the errors by10% at a peak time.

(2)If the battery energy is within 50% of max capacity, the battery is charged at the night-time.

(3)P_0 which is target of receiving power from utility is calculated to cut the peak part of the forested load curve as shown in Fig.7.

(4)If the receiving power exceeds P_0, battery starts to discharge the amount of excess.

(5)When the receiving power is less than P_0 and PV is generating and the battery energy is not full, the battery is charged by PV generation.

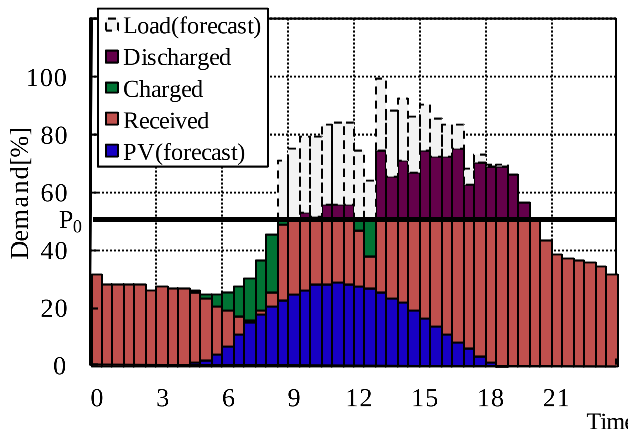

Fig.7 Calculating the target (P_0) of receiving power

D. Procedure for the hour by hour simulation

The capacity of BESS and PV generation are estimated from a viewpoint of cost and CO2-emission. This cost includes the specific electricity rates (yen/kWh) of receiving power from utility, and the basic electricity rate (yen/kW) which is influenced by the maximum electric power through a year.

The procedures of hour by hour simulation are as follows;

(1)The efficiency of PV generation is changed by the maximum temperature of each day.

(2)The amount of PV generation of each day is decided considering the efficiency depending on temperature.

(3)The load and PV generation power are forecasted. (In this paper, the errors of forecasted result are within 10%)

(4)The amount of receiving power and maximum receiving power through a year are calculated by installing PV generation and BESS.
(5)Then the total cost and total amount of CO2 emission are calculated with the coefficients as shown in Table.1.
(6)The reduction of cost and CO2 emission are calculated by installed PV generation and BESS.
(7)The procedure from (1) through (6) is repeated, until the capacity of PV generation is 30% of peak demand, and the capacity of BESS is 20%.

Table.1 Coefficients of cost and CO2-emisiion

	Day time	Night time
CO2 coefficient [kg/kWh]	0.462	0.435
Specific Electric Charge [yen/kWh]	14.56	9.2
Basic Erectric Charge [yen/kW/year]	19,656	
PV Cost [yen/kW/year]	30,000	
Battery Cost [yen/kW/year]	13,000	

E. The results of annual simulation

The results of annual simulation of one hundred times are shown in Fig.8 and Fig.9. These show improvements of total cost and total CO2-emission by installing BESS. Then installed capacity of PV generation is 14% of peak demand.

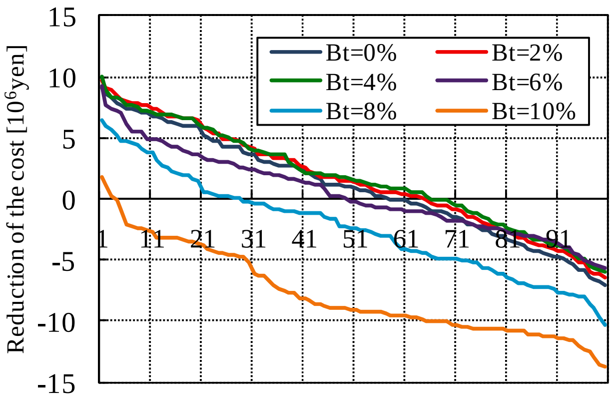

Fig.8 Reduction of total cost by installing BESS (PV=14%)

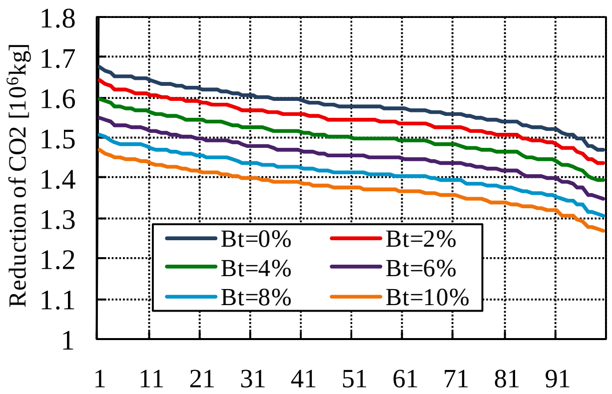

Fig.9 Reduction of total CO2 by installing BESS (PV=14%)

As the improvement of total cost, it is reduced in many cases until the capacity of BESS of 6%. However, the improvement decreases if BESS is introduced more. On the other hand, the more BESS is introduced, the more the reduction of CO2-emission decreases. This is because there is power loss at the charge/discharge of energy.

The results of annual simulation by changing capacity of PV generation are shown in Fig.10 and Fig.11. The improvement changes by installing PV and BESS. The reverse power flow appeared if PV is installed more than 16% of peak demand. In Fig.10, the total cost cannot be improved by adding capacity of BESS. This means that the load leveling is not effective if BESS is introduced more than enough.

As the improvement of CO2-emission, the CO2-emission is reduced in proportion to the installed capacity of PV generation. However, it is not reduced by installing BESS due to the power loss at the charge/discharge of energy. Therefore, the optimal installation capacities of PV and BESS are 10~15% (PV) and 2~3% (BESS) of peak demand.

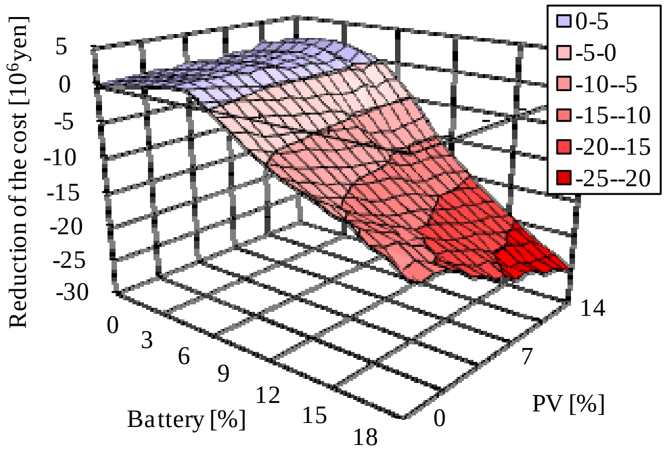

Fig.10 Reduction of total cost depending on BESS and PV

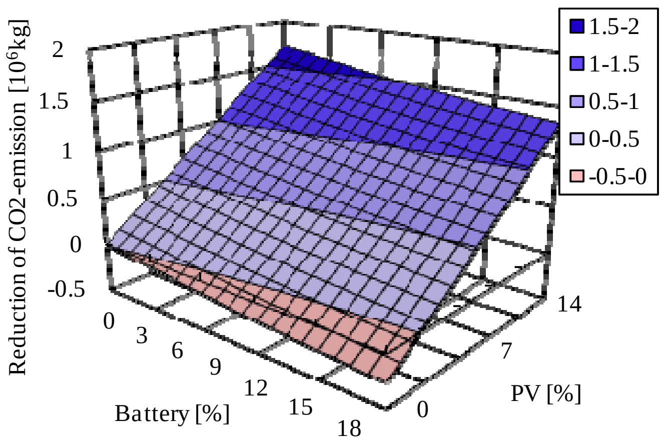

Fig.11 Reduction of total CO2 depending on BESS and PV

IV. CONCLUSION

In this paper, two subjects were discussed. First, the optimal installing condition of PV panels was investigated. The parameters of the installing condition for PV generation are tilt angle and azimuth. As a result, southward with the tilt angle of 30-50° is efficient to receive the more solar radiation annually.

In the second, the optimal installation capacities of PV generator and BESS were calculated in demand side from the viewpoint of cost and CO2-emission. These annual simulations include the load forecasting, the output forecasting of PV generation and the operation control of BESS. As the result of hour by hour simulation, the reverse power flow appeared if PV is installed more than 16% of peak demand. The optimal installation capacities of PV and BESS are 10~15% (PV) and 2~3% (BESS) of peak demand. However, this installation capacity may change by changing the error of forecasting, operation control of BESS and the shape of load curve. These are our works in the future.

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BIOGRAPHY

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