Smoothing Effect of the Power Fluctuation in Large Scale Mega Solar and Wind Turbine Hybrid Power Plant

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***Abstract*—Tahara Solar Wind Power Plant is a hybrid power plant of photovoltaic power (50 MW) and wind power (6 MW). It was built for operation in Tahara city, Aichi prefecture, Japan on October 2014. Consideration of the output fluctuation for both solar power and wind power is an important issue for the operation of the power grid. In this paper, the smoothing effect due to the combination of the photovoltaic power and the wind power is evaluated quantitatively. The in-site smoothing effect of the large scale photovoltaic power plant is also discussed.**

Keywords-Photovoltaic Power; Wind Turbine; Smoothing Effect; Maximum Power Fluctuation Level

I. INTRODUCTION

Tahara Solar Wind Power Plant is located at Tahara-city, Aichi prefecture, Japan and a hybrid power plant of photovoltaic (PV) power (50MW) and wind turbine (WT) power (6MW). Total capacity of power conditioning system (PCS) for PV power plant is 35 MW which is less than the total capacity of PV panels. Fig. 1 shows the aerial photograph of Tahara Solar Wind Power Plant.

Tahara Solar Wind Power Plant was built as a joint project by Toshiba Corp. and the other 6 companies [1] on October 2014. Since then, Toshiba Corp. and the power grid operator Chubu Electric Power Co., Inc. have been investigated for the operation conditions and characteristics of power fluctuations. The estimation and prediction of the fluctuation level are important issues for the development and popularization of the renewable energy [2, 3].

The output of PV power plant is largely fluctuated with the change of solar irradiation. However, the fluctuation becomes smaller statistically by the synthesized output fluctuations from many PV plants, which is called smoothing effect.

In case of a large PV power plant, there is a possibility that the fluctuation becomes smaller compared to a small PV power plant due to the inhomogeneity of the solar irradiation or the cloud movement over the plant site. In this paper, we call this effect "in-site smoothing effect".

This paper investigates the in-site smoothing effect in a large scale PV power plant. Furthermore, the feature of Tahara Solar Wind Power Plant is providing comparatively large capacity of WT power generation. The output of WT power is also fluctuated by the change of the wind velocity. Therefore, the power fluctuation by the combination of PV power and WT power can be also smoothed. In this paper, the smoothing effect due to the combination of PV power and WT power is also evaluated quantitatively.

Figure 1. Aerial View of Tahara Solar Wind Power Plant

II. Characteristics of Power Output

A. Evaluation of the Flucuation Level

The fluctuation level of the output power from the PV or WT power plant is evaluated by the maximum power fluctuation width (MPFW). MPFW is defined as the difference between the peak and the bottom of power outputs in a certain time window. Therefore, MPFW can be expressed as a function of the time and time window.

The fluctuation level of PV or WT power output is evaluated by MPWF at the given time scale. For example, the standard deviation of frequency distribution of MPFW during the given period is used.

Fig. 2 shows the characteristics of the photovoltaic power output of Tahara Solar Wind Power Plant. Fig. 2-a) shows the waveform of output power on February 13 in 2015. The maximum power is limited by the maximum capacity of PCSs. The sampling time is 5 second in this case. Fig. 2-b) represents the distribution of MPFW during the daylight time for the same day as Fig. 2-a). Horizontal axis denotes the power fluctuation level (MPFW) where the time window is 20 minutes. It is seen that the shape of distribution is far from the normal distribution and there are two peaks. Therefore, we adopt the 95 percentile point in addition to the standard deviation for the evaluation of the fluctuation level. In this case, the standard deviation is 8.72 MW and 95 percentile point is 27.38 MW.

Fig. 3 shows the example of the evaluation of the MPFW of WT power output of Tahara Solar Wind Power Plant on the same day as Fig. 2. The sampling time is same as PV power output. Fig. 3-b) represents the frequency distribution of the power fluctuation during the whole day. Time window is also 20 minutes, which is same as Fig. 2. The maximum power output is 6 MW. In this case, the standard deviation is 0.927 MW and 95 percentile point is 3.11 MW. It can be said that the WT generate more short-time fluctuation compared to the PV.

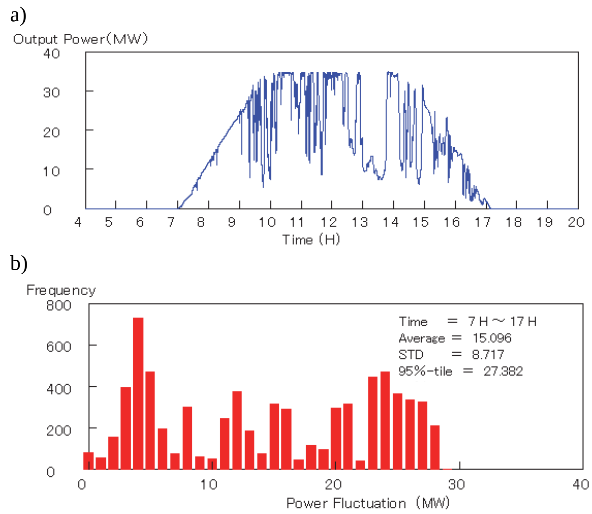


Figure 2. PV Power Output and its Fluctuations of Tahara Solar Wind Power Plant on Feburary 13 in 2015.
a) Waveform of Power Output, b) Frequency Distribution of Power Fluctuations when Time Window is 20 Minutes.

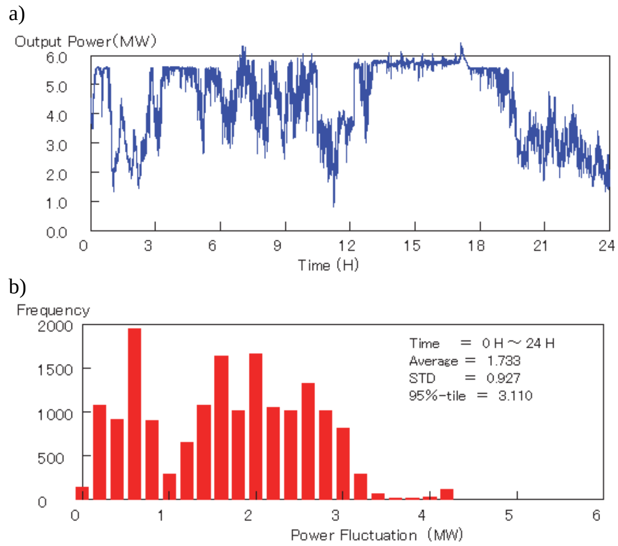


Figure 3. WT Power Output and its Fluctuations of Tahara Solar Wind Power Plant on Feburary 13 in 2015.
a) Waveform of Power Output, b) Frequency Distribution of Power Fluctuations when Time Window is 20 Minutes.

B. Distribution of the Power Output in the Site

The output power in the large scale PV power plants changes by the position of the PV panels. In this paper, we divide the large scale PV power plant into small parts in order to investigate the in-site smoothing effects. Fig. 3 shows the schematic drawing of the Tahara Solar Wind Power Plant. The numbers of Fig.4 are corresponding to the group of PCSs whose total power is 1 MW.

Fig.5 shows the output power distribution at 14:08 of October 21 in 2014. It is seen that the output power changes by the location of the site.

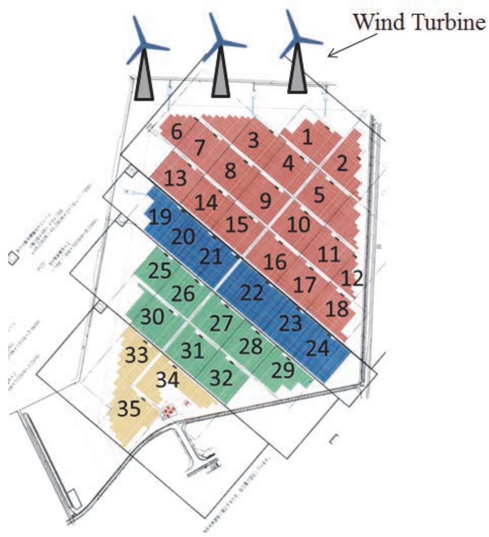


Figure 4. Schematic drawing of the Tahara Solar Wind Power Plant.

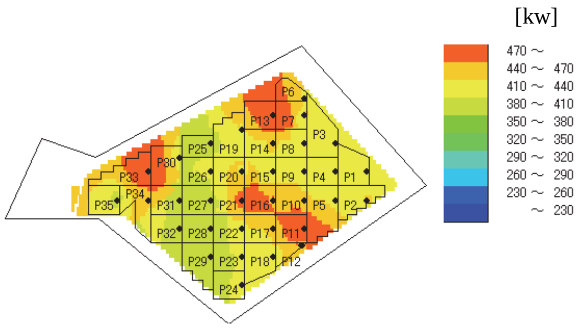


Figure 5. Power Output Distribution in the Site.at 14:08 of October 21 in 2014.

III. Analysis of Smoothing Effects

A. *In-Site Smoothing Effects*

The main purpose of this paper is to demonstrate the simultaneous smoothing effect between PV power and WT power. At first, we evaluate the smoothing effect by PV output only. We define the smoothing effect rate R as the following equation;

$$R = \left(\sum_{i=1}^{N}(W_i - W_{TOT})\right) / \frac{1}{N}\sum_{i=1}^{N} W_i \qquad (1)$$

Here, N is a number of areas, W_i is the average of MPFW within one hour for the output at i-th area and W_{TOT} is the average of MPFW within one hour for the total output, respectively. Figure 6 shows the calculation results of the smoothing effect rate R for the time widow from 30 second to 20 minute are shown. It is found that the smoothing effect rate is up to 50 % in case of time window of 30 seconds.

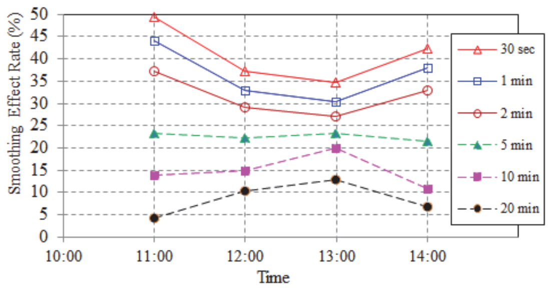


Figure 6. Smoothing Effect Rate for the Various Time Windows

B. *Simultaneous Smoothing Effects between PV and WT*

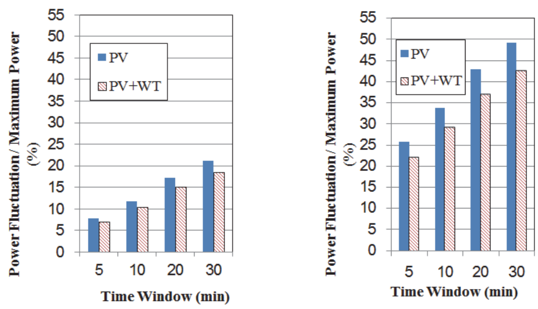
It is thought that the correlation between the amount of the solar radiation and the wind velocity is comparatively low. Generally, the smoothing effect is large when the independency of the signals is high. Therefore, the power fluctuation by the combination of the PV power and WT power is considered to be smoothed. However, the simultaneous smoothing effect by the combination of the PV power and WT power has not been well investigated. In this section, we evaluate the simultaneous smoothing effect between the PV power and WT power.

Fig.7 shows the results of the simultaneous smoothing effect. Fig.7-a) shows the average of power fluctuation level normalized by the maximum output power for the PV output only and PV+WT case. Fig.7-b) shows the case when 95 percentile point is used for the fluctuation level. In both cases, the fluctuation level of PV+WT is smaller than that of PV only case.

In order to estimate the smoothing effect by the combination of PV output and WT output, we define the simultaneous smoothing effect rate R_{PV+WT} as follows;

$$R_{PV+WT} = 1 - \left(\frac{\text{Fluctuation level of total output of PV + WT}}{\text{Fluctuation level of PV output only}}\right) \qquad (2)$$

TABLE 1 summarizes the calculation results of the simultaneous smoothing effect rate. The simultaneous smoothing effect rate is 8.3%~12.3% for the average fluctuation and about 13% for 95 percentile point. Since the correlation of output fluctuation of PV and WT is small, the difference of annual average value of MPFW between PV only and PV+WT case is small (applox. 0.2MW) by any time window. Furthermore, since the PV capacity is about 6 times larger than the WT capacity in Tahara Solar Wind Power Plant, the effect of output fluctuation of PV is dominant for 95 percentile point. Therefore, the 95 percentile point is almost constant.



(a) Average (b) 95 Percentile

Figure 7. Time Window and Power Fluctuation Rate

TABLE I. Smoothing Rate by PV Power and Wind Power

Time Window	Smoothing Effect Rate (%)	
	Average	***95 Percentile***
5 min	8.3	13.7
10 min	10.5	13.2
20 min	11.8	13.5
30 min	12.3	13.6

IV. Conclusion

In this paper, the smoothing effect due to the combination of the photovoltaic power and the wind power is evaluated quantitatively. It is found that simultaneous smoothing effect rate increases with the time scale and up to about 12 ~ 13%.

References

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