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ESTIMATION OF BATTERY CAPACITY FOR SUPPRESSION OF A PV POWER PLANT OUTPUT FLUCTUATION

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ABSTRACT

Demonstration project named “Verification of Grid Stabilization with Large-scale PV Power Generation” has been conducted by the New Energy and Industrial Technology Development Organization (NEDO). In the Wakkanai PV power station, Sodium-Sulfur battery system is introduced to realize some additional functions. Since fluctuation in output of MW-class PV system may disturb the stable operation of power station, it is important to develop a fluctuation suppression technology. The authors have developed a fluctuation suppression using a battery system. In this paper, the relation between available battery capacity and fluctuation suppression performance is analyzed by computational simulation. This paper also estimates and discusses required battery capacity for fluctuation suppression.

INTRODUCTION

Utilization of renewable energy such as a photovoltaic generation (PV) is important to reduce the CO_2 emissions. The Japanese government has set 4,820[MW] as a target for PV installation by FY2010. However, the total installed capacity by the end of FY2008 was only 2,144[MW][1]. In order to achieve the target, further installation in residential sectors and construction of large-scaled PV systems are required. Fluctuation in output of large-scaled PV system may disturb the stable operation of power system, especially frequency control. In the small power system, like Japanese power system, it becomes more serious issue. That is, realization of fluctuation suppression for generation output is one of the important factors. One of the promising technologies to suppress the PV output fluctuation caused by unstable solar radiation is to utilize an energy storage system. The New Energy and Industrial Technology Development Organization (NEDO) in Japan has started a demonstrative research project on large-scaled PV generation system since FY2006. This project, named “Verification of Grid Stabilization with Large-scale PV Power Generation” has been conducted at Wakkanai city, Hokkaido prefecture and Hokuto city, Yamanashi prefecture in Japan. One of the main purposes of this project is to develop a technique for realizing fluctuation suppression operation of PV power station. In this paper, relation between power capacity of battery system and fluctuation suppression performance is analyzed. This paper also estimates required energy capacity of battery system for satisfying the assumed fluctuation suppression requirement.

OUTLINE OF WAKKANAI POWER STATION

Schematic configuration of the Wakkanai PV power station is shown in Figure 1. In Wakkanai PV power station, 5.02MWp PV arrays and 1.5MVA x 7.2h Sodium-Sulfur (NAS) battery system have been installed. These equipments are controlled by the output control system based on the data acquired from the measurement system and future solar radiations predicted by the radiation forecast system.

FLUCTUATION SUPPRESSION METHOD

In the Wakkanai PV power station, the NAS battery system is utilized to suppress short-term fluctuation in PV output. Schematic image of fluctuation suppression is shown in Figure 2.

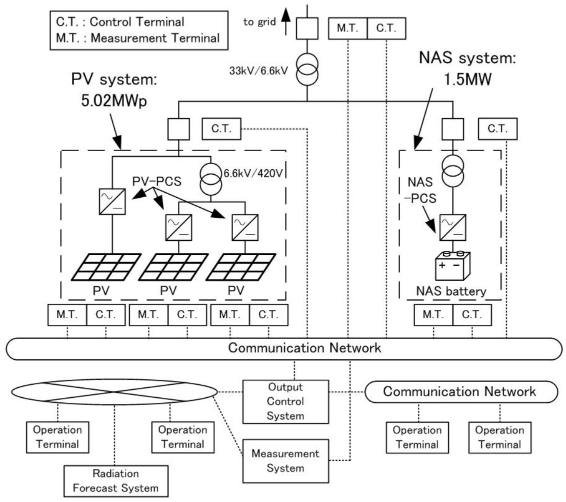

Figure 1 Outline of Wakkanai Power Station.

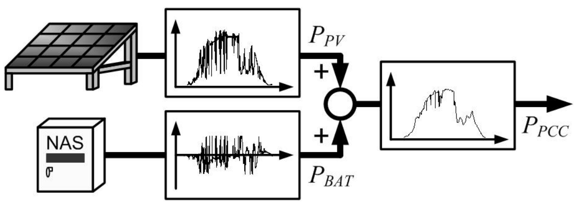

Figure 2 Image of Fluctuation Suppression.

This can be achieved by setting the NAS battery system output (P_{BAT}) to difference between reference for power station output (P^*_{PCC}) and PV output (P_{PV}) as you can see in Figure 3. Here, the NAS battery system should be operated within its power capacity (P_{MW}). Therefore, a limiter is employed in Figure 3 to satisfy $-P_{MW} \le P_{BAT} \le P_{MW}$. In the later computational simulations, dynamic response of NAS battery is not considered since the battery can work rapidly comparing to the control interval (1[s]). The following two methods for setting P^*_{PCC} are assumed and compared in this paper.

Moving Average Method

In the moving average method (MA), the reference for station output at k-th control interval ($P^*_{PCC}(k)$) is set to the moving average (sampling time is 1[s], averaging time is T_{MA}[s]) of P_{PV} as equation (1).

$$P^*_{PCC}(k) = \frac{1}{T_{MA}} \sum_{i=1}^{T_{MA}} P_{PV}(k-i) \tag{1}$$

Longer T_{MA} makes the short-term fluctuation of P^*_{PCC} smaller, however, it also elongates the time delay of P^*_{PCC} to P_{PV}. Longer time delay requires larger P_{BAT}. As a result, too long averaging time increases the risk of power capacity violation and deteriorates the fluctuation suppression performance. The MA can work with relatively small variation of SOC (State Of Charge) since the summation of P^*_{PCC} along the day is equal to the daily summation of P_{PV}. This feature makes the SOC management easier.

Hybrid Method

The authors have developed the fluctuation suppression method which can work with small power capacity of NAS battery system. In the proposed method, called hybrid method (HY), two types of P^*_{PCC} calculation procedure, the MA and the fluctuation center following (FCF) are used selectively according to the fluctuation magnitude of P_{PV}.
The FCF works well for large fluctuation. Basic idea of the FCF is to set the P^*_{PCC} to the center of fluctuation. More specifically, the FCF set P^*_{PCC} to mean of maximum value and minimum value of P_{PV} as you can see in Figure 4. If the P^*_{PCC} is increased by 50[kW] from the mean value, required P_{MW} also increases by 50[kW] since the required P_{MW} for discharge is increased by 50[kW]. That is, the mean of maximum and minimum values of P_{PV} is best for P^*_{PCC} from the power capacity minimization perspective. However, the maximum and minimum values of P_{PV} are not available online. The FCF estimates them from the past P_{PV}. From the estimated maximum and minimum values of P_{PV} during the last T_{FCF}[s], the P_{PCCF} is calculated by equation (2).

$$P_{PCCF}(k) = \frac{\max_{j \in T} P_{PV}(k-j) + \min_{j \in T} P_{PV}(k-j)}{2} \tag{2}$$

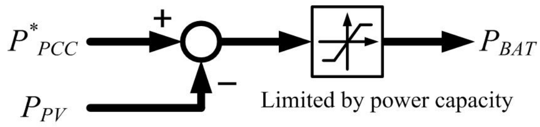

Figure 3 Setting of P_{BAT}.

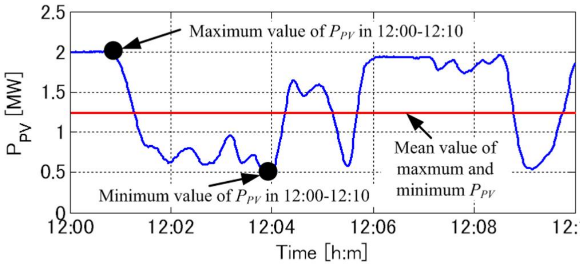

Figure 4 Mean Value of Maximum and Minimum P_{PV}.

here, T={1,2, … ,T_{FCF}}.
The FCF works well for large fluctuations in P_{PV}, however, it may require wider variation of SOC than the MA. Therefore, the FCF should not be applied for small fluctuation. The HY selectively switches the fluctuation suppression method based on the equations (3) and (4).

$$P^*_{PCC}(k) = \begin{cases} P_{PCCF}(k) & (P_{FR}(k) \ge P_{TH}) \\ \dfrac{1}{T_{MA}} \displaystyle\sum_{i=1}^{T_{MA}} P_{PV}(k-i) & (P_{FR}(k) < P_{TH}) \end{cases} \tag{3}$$

$$P_{FR}(k) = \max_{j \in T} P_{PV}(k-j) - \min_{j \in T} P_{PV}(k-j) \tag{4}$$

Here, the P_{TH} is the threshold for mode shifting. The $P_{FR}(k)$ is the estimated fluctuation magnitude and is defined as the difference between maximum and minimum value of P_{PV} during the last T_{FCF}. The FCF uses $P_{PCCF}(k)$ as P^*_{PCC} only when the $P_{FR}(k)$ is larger than the P_{TH}. In order to avoid the large variation in $P^*_{PCC}(k)$ caused by suppression mode shifting, a rate limitation for P^*_{PCC} (setting value is dP^*_{PCC}/dt) is introduced.

POWER CAPACITY OF NAS BATTERY AND SUPPRESSION PERFORMANCE

Index for Output Fluctuation

In order to discuss the relation between the power capacity of NAS battery and fluctuation suppression performance, the authors have run computational simulation in which the actual PV output data measured at the Wakkanai PV power station during 140 days from April 2008 to September 2008 (sampling time is 1[s]) are used. Note that the PV arrays of 2[MWp] were available in the above period. Since the discussion in this chapter focuses on the power capacity of NAS battery, the energy capacity of NAS battery was considered as infinite.
The suppression performance is evaluated in terms of maximum fluctuation range. The fluctuation range is defined by difference between maximum and minimum

value of P_{PCC} in a specified duration (T_W). Maximum value of these in all days is the maximum fluctuation range (ΔP_{PCC}). Since this paper focuses on the short-term fluctuation range, we applied three T_W (1[min], 10[min], 30[min]).

Estimated Performance of MA

Blue plots in Figure 5 show the estimated performance of MA measured with T_W=10[min]. Here, the T_{MA} was also treated as a parameter in the estimation. As shown in Figure 5, it is clear that larger P_{MW} can realize better suppression performance (smaller ΔP_{PCC}). We can also find that the best performance (minimum ΔP_{PCC}) can be achieved when the T_{MA} of 30[min] is applied. This result indicates that T_{MA}=30[min] is the optimal for reducing the ΔP_{PCC} measured with T_W=30[sec]. But optimal T_{MA} may be changed by T_W, so T_{MA} should be selected with care.

Estimated Performance of HY

Same estimation was conducted for the HY. Also in this estimation, the T_{MA} is treated as parameter and the other parameters are fixed (T_{FCF}=30[min], dP^*_{PCC}/dt=1[s], P_{TH}=800[kW], dP^*_{PCC}/dt and P_{TH}, all are set by trial and error). The estimated performance is illustrated as red plots in Figure 5; From this estimation result, we can say that the HY can maintain almost same performance level as the MA against the longer TMA; however, for the shorter TMA, it can realize slightly better performance.

REQUIRED NAS BATTERY CAPACITY FOR THE ASSUMED SUPPRESSION PERFORMANCE

Required Power Capacity

In this chapter, let us assume that the PV power station owner must satisfy fluctuation suppression requirement which regulates the admissible level for ΔP_{PCC} (ΔP_{PCCr}). Under this situation, the P_{MW}, T_{MA}, T_{FCF} which can satisfy this requirement are calculated in this section. In detail, the required power capacity is estimated as the least P_{MW} which can realize the ΔP_{PCCr} in Figure 5. Estimated required P_{MW} is shown in Figure 6. Since a large ΔP_{PCCr} means loose requirement, the required P_{MW} can be reduced. Figure 6 also shows that P_{MW} of HY is smaller than or equal to one of MA.

Required Energy Capacity

Our past investigations revealed that longer T_{MA} or T_{FCF} enlarges the required energy capacity (E_{MWh}). Therefore, the shortest T_{MA} or T_{FCF} is adopted if some candidates are found in the power capacity estimation process. Based on the estimated power capacity and time constants, the required E_{MWh} is estimated. More specifically, through the time sequential simulation using the estimated power capacity and time constants, the loci of SOC is calculated. Then, the required E_{MWh} is obtained as a variation range of

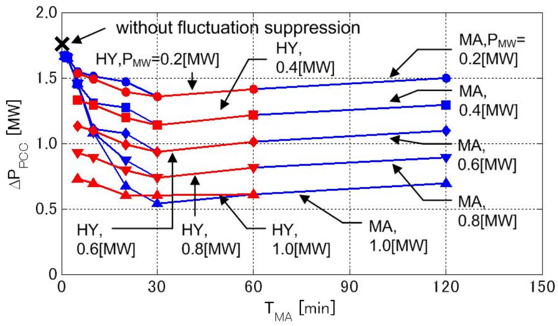

Figure 5 Relation between T_{MA}, P_{MW}, and ΔP_{PCC}.

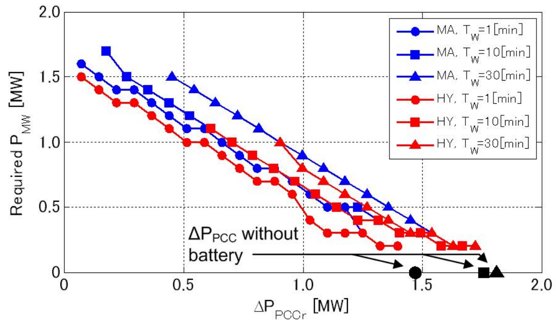

Figure 6 Required P_{MW} to satisfy ΔP_{PCCr}.

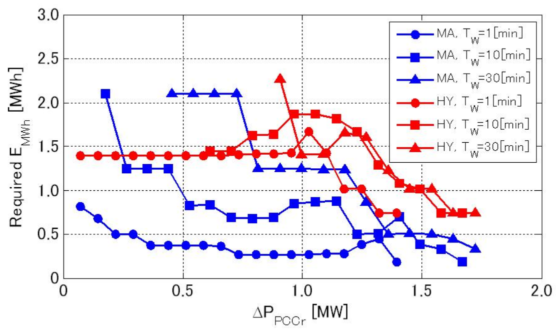

Figure 7 Required E_{MWh} to satisfy ΔP_{PCCr}.

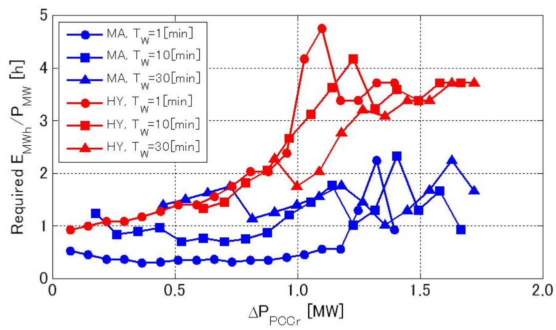

Figure 8 Required E_{MWh}/P_{MW} to satisfy ΔP_{PCCr}.

daily SOC locus. The assumptions applied in the time sequential simulation are;

- No limitation on energy capacity during the time sequential simulation
- Efficiency of charge/discharge is 85[%] (when the S[MWh] is charged (measured at the ac side of battery), only 0.72S[MWh] can be discharged to the ac side)

Figure 7 shows the calculated required E_{MWh}. As shown in this Figure, smaller ΔP_{PCC} (severe requirement condition) requires larger E_{MWh}. It is also ascertained that the HY requires larger E_{MWh} than the MA.

Generally, the ratio of energy capacity to power capacity is specified by the physical or chemical nature of battery. In order to identify the suitable battery for fluctuation suppressing, the ratio of E_{MWh} to P_{MW} (E_{MWh}/P_{MW}) is calculated based on Figures 6 and 7. The obtained E_{MWh}/P_{MW} is shown in Figure 8. As you can see this estimation result, the E_{MWh}/P_{MW} ranges from 0.3[h] to 2.3[h] in the MA and from 0.9[h] to 4.8[h] in the HY.

CONCLUSION

This paper focused on the large-scale PV power station which utilizes the battery for output fluctuation suppression. Relation between power capacity of battery and output fluctuation suppression performance was analyzed through computational simulations considering two suppression techniques; the MA and HY.

This paper also discusses the required energy capacity of battery based on the assumed suppression requirements.

ACKNOWLEDGEMENT

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