# An Evaluation of Area-dependency Equalization of Fluctuation Characteristics from Distributed PV Systems

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Short time fluctuations of solar irradiance will become an important issue with regard to future embedded photovoltaic (PV) systems. However, when a large number of systems introduce in certain area intensively, the output of the systems will be stable by the equalization of irradiance fluctuation. This phenomenon is called “the smoothing effect” by the authors. In this paper, the evaluation method of fluctuation of PV output is described. By using this evaluation method, frequency characteristics of PV output are evaluated. Moreover, relations between the smoothing effect and installation scale of PV systems are examined.

**Keywords**: fluctuation, the smoothing effect, Wavelet transform, clustered PV system

## INTRODUCTION

An output of PV systems has a short-term fluctuation due to weather fluctuation. It may give undesirable effects on an individual power system, and it makes the capacity value (kW value) of the PV system lower. For resolution of those problems, authors have studied “the smoothing effect” which is smoothed total irradiance in the area. Fluctuation of output of a few PV systems is sensitive, but fluctuation of total output in clustering PV systems is not remarkable because there is the smoothing effect of irradiance in certain area. According to the smoothing effect, the capacity value of PV systems is increased, and problems for utility occurred by fluctuation of PV output power can be alleviated. Therefore, it is very important to quantify this effect and to develop the evaluation method. In this study, the evaluation method of smoothing effect of PV systems is proposed by frequency analysis: i.e. Wavelet transform. Frequency analysis is useful to identify fluctuation values of each time scales. Over the last few years, authors have developed this method [1], [2]. In this paper, by using this method, the evaluation result of fluctuation characteristics of PV output is described. Moreover, relations between the smoothing effect and installation scale of PV systems are examined.

## MEASURED DATA

Irradiance and PV output data 553 PV systems clustered will be measured every second as the part of NEDO’s project, “Demonstrative Research on clustered PV Systems” from March, 2004, to March 2008. Therefore, measured data has been recorded by one second sampling. PV array power was used for this analysis.

## APPROACH

### Fluctuation Analysis

In an evaluation of fluctuation characteristics of PV output, it is necessary to know the relation between speed of fluctuation and magnitude of fluctuation. Therefore, a new method is suggested to analyze the fluctuation (see Fig.1.).

First, analytical data is prepared, and the power spectrum (PS) is calculated from this data by using the Wavelet transform. Haar has been chosen as a wavelet function. Next, the peak of PS is detected for each range of fluctuation time (see Table.1.). An evaluation window is prepared centering on the peak of PS as shown in Fig. 2, and the difference between the maximum value and minimum value in the window is calculated. This difference is defined as Maximum magnitude of the fluctuation (MMF). MMF shows the biggest magnitude of fluctuation during a day for each range of fluctuation time. In other words, this is the worst case in the fluctuation.

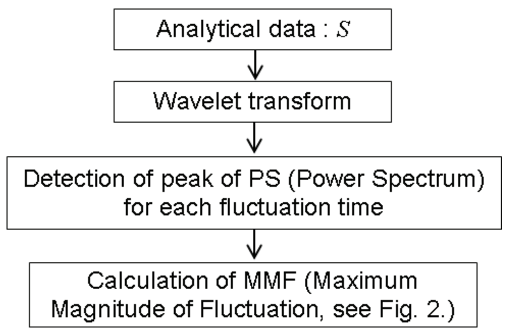


Fig. 1. Fluctuation analysis flow.

Table. 1. Range of fluctuation time.

| Level j | Range of fluctuation time ($2^j$ ~ $2^{j+1}$) [sec] | Frequency [Hz] |
|---|---|---|
| 1 | 2 ~ 4 | 0.5 ~ 0.25 |
| 2 | 4 ~ 8 | 0.25 ~ 0.125 |
| 3 | 8 ~ 16 | 0.125 ~ 0.0625 |
| 4 | 16 ~ 32 | 0.0625 ~ 0.03125 |
| 5 | 32 ~ 64 | 0.03125 ~ 0.01562 |
| 6 | 64 ~ 128 | 0.01562 ~ 0.00781 |
| 7 | 128 ~ 256 | 0.00781 ~ 0.00390 |
| 8 | 256 ~ 512 | 0.00390 ~ 0.00195 |
| 9 | 512 ~ 1024 | 0.00195 ~ 0.00097 |
| 10 | 1024 ~ 2048 | 0.00097 ~ 0.00048 |
| 11 | 2048 ~ 4096 | 0.00048 ~ 0.00024 |
| 12 | 4096 ~ 8192 | 0.00024 ~ 0.00012 |
| 13 | 8192 ~ 16384 | 0.00012 ~ 0.00006 |
| 14 | 16384 ~ 32768 | 0.00006 ~ 0.00003 |
| 15 | 32768 ~ 65536 | 0.00003 ~ 0.00001 |

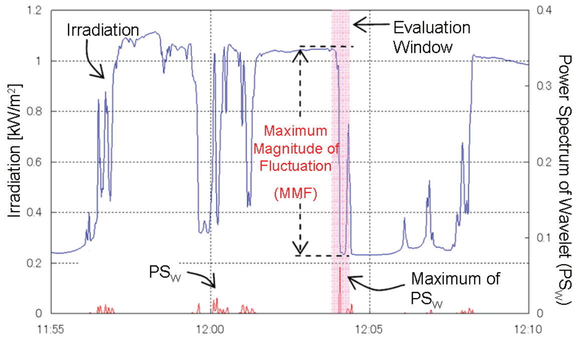


Fig. 2. Example of calculating MMF.

## An evaluation method of the smoothing effect

The data of some PV systems are necessary to evaluate the smoothing effect. The data of 60 PV systems in red dotted line of Fig.3. was used this time. Moreover, increasing pattern of number PV systems becomes important in this evaluation. A swirling arrowed line in Fig.3. shows increasing pattern of number PV systems. In this analysis, number of PV systems is increased one-by-one by using this increasing pattern.

Fig.4. shows an evaluation flow of the smoothing effect. First, measured data of 60 PV systems are prepared. Next, measured data of PV array power is divided by rated capacity of PV array, and normalization. This reason is that capacity of PV array is different in each PV systems. Next, when n (number of PV systems) is two or more, those data is averaged. It is thought that the more n increases, the more the smoothing effect influences averaging data. This averaging data becomes an input data of the fluctuation analysis of Fig.1. Finally, these processes are repeated 60 times.

In the evaluation of the smoothing effect, number of installation of the PV system and installation area of the PV system is important. However, only number of installation of the PV system is discussed in this analysis. Note that the influence of installation area of the PV system is included.

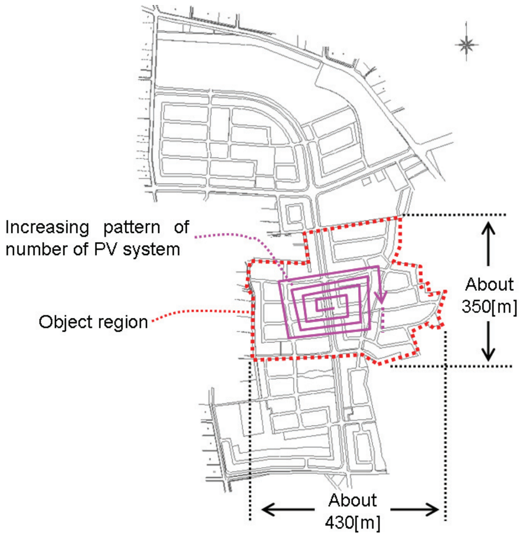


Fig. 3. Increasing pattern of number of PV systems.

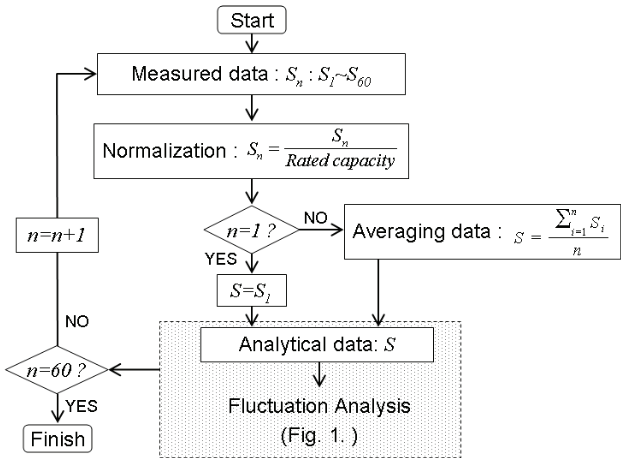


Fig. 4. An evaluation flow of the smoothing effect.

## RESULTS AND DISCUSSION

In this paper, fluctuation characteristics of three typical weathers (Fig.5, 8, and 11) are discussed. The weather was selected referring to reference [3]. Clearness Index (CI) 0.5 is fluctuation day, CI 0.39 is cloudy day, and CI 0.69 is clear day.

When the number of PV systems was increased from 1 system to about 60 systems, MMF was calculated each fluctuation time. Analyzed results are shown as follows. Fig.6, 9, and 12 show the relation between MMF and fluctuation time when the number of PV systems is 1, 10, 40 and 60. Fig. 7, 10, and 13 show the relation between MMF and number of PV systems when fluctuation time is from 2 to 128 seconds.

**Fluctuation day (Clearness Index: 0.50)**

As for the irradiance on this day, the fluctuation magnitude is large, and the fluctuation speed is fast. In Fig.6, short time fluctuation of output becomes small in 60 systems, though one system fluctuates wildly the output. This reason is that the fluctuation of each PV system for a short time has not synchronized. In Fig.7, it is seen that MMF tend to decrease in ranges of 2-32 seconds at fluctuation time as the number of PV systems increased. The characteristics of MMF showed a flat characteristic for 64 seconds or more the fluctuation cycle. Therefore, the smoothing effect was effective at 32 seconds or less.

**Cloudy day (Clearness Index: 0.39)**

As for irradiance on this day, fluctuation is small and slower than the fluctuation day. In Fig.9, there is little difference of one system and 60 systems in fluctuation characteristic. This reason is that the fluctuation of each PV system has almost synchronized. In Fig.10, it seen to that MMF is constant regardless of number of PV systems. This means the smoothing effect has not occurred. However, the fluctuation for a short time will not become a problem any more than fluctuation day, because it is smaller than fluctuation day.

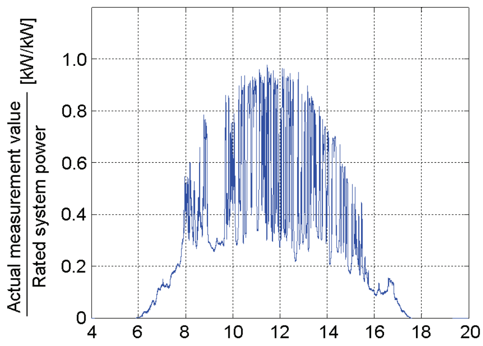


Fig. 5. Normalized PV array output power.
(Clearness Index: 0.50, 14 May 2005)

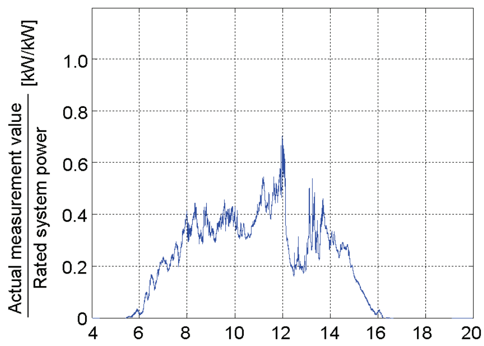


Fig. 8. Normalized PV array output power.
(Clearness Index: 0.39, 1 May 2005)

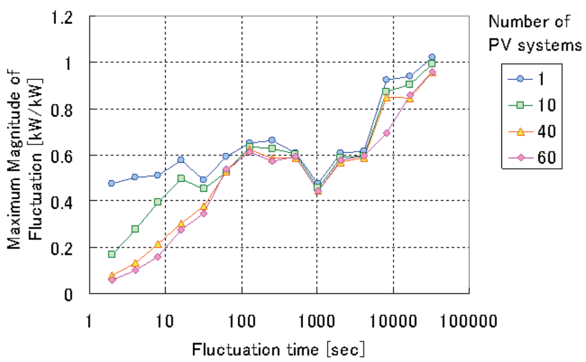


Fig. 6. Relation between MMF and fluctuation time.
(Clearness Index: 0.50, 14 May 2005)

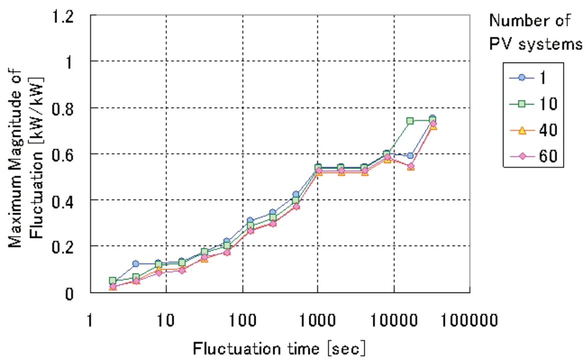


Fig. 9. Relation between MMF and fluctuation time.
(Clearness Index: 0.39, 1 May 2005)

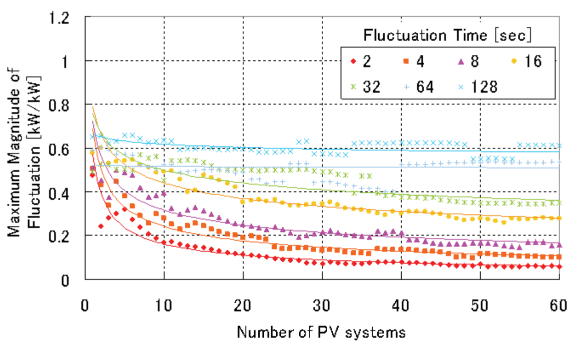


Fig. 7. Relation between MMF and number of PV systems. (Clearness Index: 0.50, 14 May 2005)

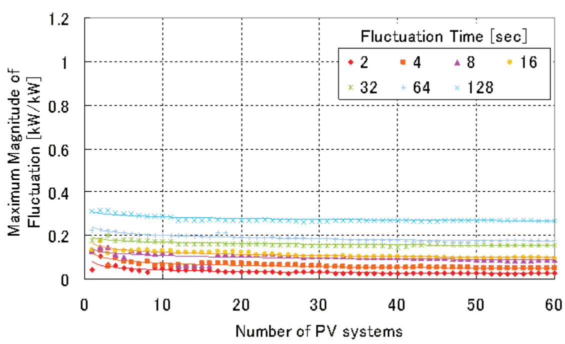


Fig. 10. Relation between MMF and number of PV systems. (Clearness Index: 0.39, 1 May 2005)

**Clear day (Clearness Index: 0.69)**

As for irradiance on this day, this irradiance is basic curve of irradiance, and has no fluctuation by the cloud. In Fig.12, there is no difference of one system and 60 systems in fluctuation characteristic. This reason is that the fluctuation of each PV system has synchronized. In Fig.13, it seen to that MMF is near 0 [kW/kW] regardless of number of PV systems. This means the smoothing effect has not occurred, too. However, the fluctuation for a short time will not become a problem as well as cloudy day.

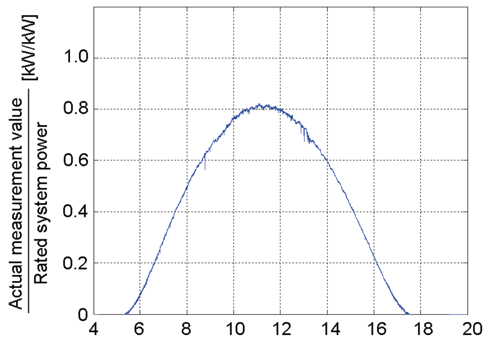


Fig. 11. Normalized PV array output power. (Clearness Index: 0.69, 4 May 2005)

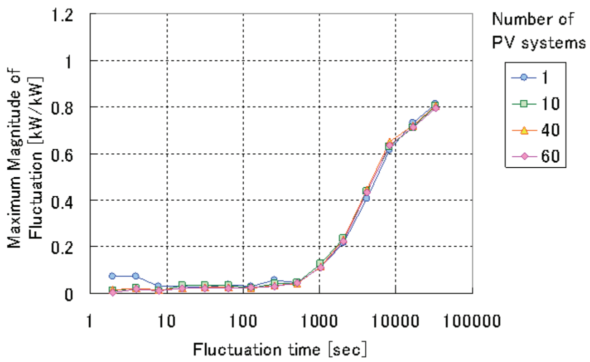


Fig. 12. Relation between MMF and fluctuation time. (Clearness Index: 0.69, 4 May 2005)

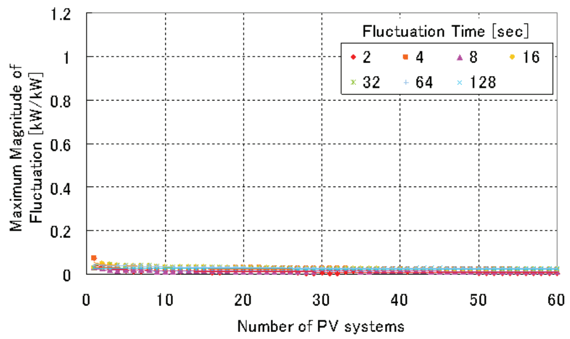


Fig. 13. Relation between MMF and number of PV systems. (Clearness Index: 0.69, 4 May 2005)

## CONCLUSIONS

Maximum Magnitude of fluctuation was defined as an evaluation index of the fluctuation characteristic. From analysis results, it was quantitatively shown that the smoothing effect occurs on the day when a short time fluctuation is large. Therefore, the smoothing effect can be clarified by this evaluation method.

In the future, the smoothing effect will be modeled based on a long-term analytical result.

## ACKNOWLEDGMENTS

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