A Malfunction Detection Method for Individual Photovoltaic Modules

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Abstract: Although photovoltaic (PV) modules occasionally fail, it is difficult to identify which module is malfunctioning. In order to detect malfunctioning PV modules, we have developed a malfunction detection method for individual PV modules by continuously monitoring their data. This method can automatically identify a malfunctioning module where output power declines at an early stage. Thus, the method provides faster and more accurate detection of malfunctions. Moreover, the method considerably reduces workloads for maintenance personnel because it eliminates the need for conventional inspection procedures to identify a malfunctioning module. A feature of the method is the utilization of two kinds of information among the PV modules, namely, spatial and temporal correlations, to distinguish between generation declines due to some malfunction and those due to climate conditions. To confirm the effectiveness of the method, we conducted a malfunction-detection experiment with actual data from our PV module monitoring system which we have already implemented. The experiment used 24 PV modules installed within the monitoring system, and simulated a malfunction by covering 10% of a module. The system was able to detect the period of the simulated malfunction, which confirms the effectiveness of the method.

1 INTRODUCTION

Photovoltaic (PV) modules are generally believed to be maintenance-free and to last for more than 20 years, but, in reality, they occasionally fail because they are industrial products. Accordingly, PV modules need to be maintained in terms of their proper timing. However, it is difficult to identify which module has a malfunction because existing PV module systems are only capable of displaying the overall level of power generation from a system on a power conditioner. In order to detect malfunctioning modules at an early stage, we have developed a malfunction detection method for individual PV modules by continuously monitoring their data.

The maintenance of PV module systems is conventionally carried out by checking the level of solar energy at a power conditioner, or by checking for abnormalities with the modules or with the cable connections, etc. at an installation (Tan and Seng, 2011). However, this method results in delays in detecting malfunctions, and, additionally, imposes heavy workloads on maintenance personnel to check each PV module in turn. Thus, recently, awareness of the need for malfunction detection techniques has been growing. For example, some studies consider automatic fault detection by continually monitoring output power data (Chouder and Silvestre, 2010; Polo et al., 2010; Stettler et al., 2006). Moreover, other studies have been developing a fault detection technique for each string (Phoenix Contact, 2012; Onamba, 2010) or a technique for monitoring and maximizing the output power from PV modules (Tigo Energy, 2009).

With the method proposed in this paper, each module is continuously monitored in order to identify as soon as possible abnormal decreases in output power that would indicate the emergence of some kind of malfunction. Thus, detecting declines in output power is fast and accurate with this method, and the workloads for maintenance personnel are considerably reduced because the method eliminates the need for conventional inspection procedures to identify a malfunctioning module. A technical feature of the method is that it can distinguish between generation declines due to some malfunction and those due to overcast or climate conditions. This is achieved by utilizing correlation information from the PV modules and

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power output data is transformed in to a form that makes it easy to detect malfunctions. We employ two kinds of correlation information; namely, spatial correlations involving comparisons among neighbour PV modules and temporal correlations involving comparisons with prior power output data.

The method utilizes a monitoring system for individual PV modules that we have already implemented (Nosato et al., 2012; Nosato et al., 2013). The system can monitor the status of each module through the installation of inexpensive dedicated transmitters and a receiver that has been developed with our original technology. Furthermore, a merit of the system is that no additional cables are required for communication purposes because the method uses the DC power lines from the PV modules as communication lines. In the present study, we conduct a detection experiment for a simulated malfunction with actual data for the PV module monitoring system, which confirms the effectiveness of the method.

2 MONITORING SYSTEM FOR INDIVIDUAL PV MODULES

The method requires a PV module system that is capable of monitoring the power generated by each module. We have already developed such a system (Figure 1) (Nosato et al., 2012; Nosato et al., 2013). This section provides an outline of the system.

The system monitors the status of power generation for each module through the installation of dedicated transmitters and a receiver (Figure 2). An important advantage of the transceivers is that the system does not require additional cables for communication, because the transceivers use the power lines from the PV modules as communication lines.

A transmitter (Figure 3) is so small that it can be installed within a junction box, and a receiver (Figure 3) is installed on the front of a power conditioner. For communication, we have developed a new method that is robust to noise by applying CDMA (Code Division Multiple Access) technology which is widely used in wireless communication, such as mobile phones. Each transmitter measures the voltage, current, and temperature levels for each PV module and transmits these data. The receiver monitors the output power, voltage, current, and temperature for all the PV modules from the data received from the transmitters. The receiver is connected to a PC, where monitoring data are displayed and saved. This system can monitor data for up to 50 modules at approximately every 18 seconds. Moreover, the transmitter can be manufactured with inexpensive commercial parts, and the manufacturing cost is estimated to be 2 to 3 U.S. dollars when mass produced.

In this study, we conduct a malfunction detection experiment for individual modules with the monitoring system.

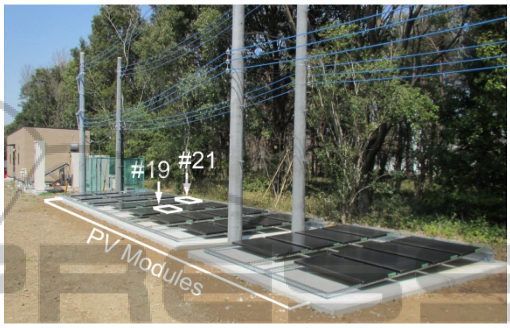

Figure 1: Photograph of the monitoring system for individual PV modules (with modules #19 and #21, used in this paper, highlighted).

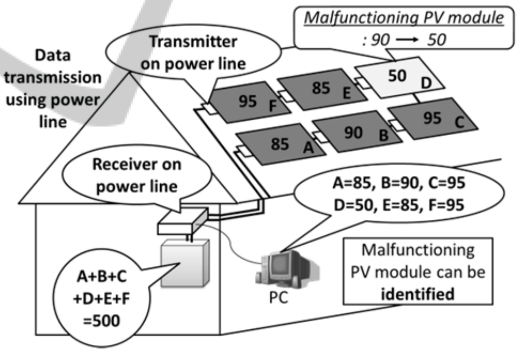

Figure 2: Overview of the monitoring system for individual PV modules.

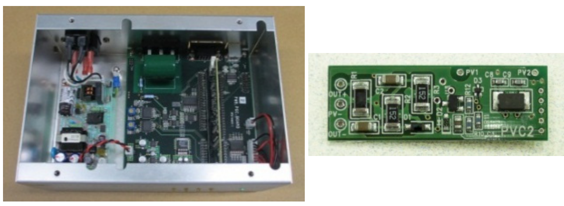

Figure 3: Transmitter (left, 197 x 140 x 75 mm) and receiver (right, 14.5 x 42.0 mm) for the PV module monitoring system.

3 BASIC CONCEPT OF MALFUNCTION DETECTION

3.1 Target Malfunction for Detection

In this section we describe the malfunction targeted for detection in this paper.

PV modules with reduced output power can be identified with this monitoring technology for individual PV modules. However, from analyses of the reasons for power fluctuations with our PV monitoring system, output levels fluctuate markedly everyday due to (1) climatic conditions (solar irradiation and cloud coverage) and (2) environmental shade from nearby buildings and trees, etc. Thus, it is necessary to distinguish between declines due to such factors and decreases due to a malfunctioning PV module.

Within this paper, malfunction refers to a range of phenomenon affecting individual modules, from faults that would require repair to normal deteriorations in performance over time, as well as reduced performance due to soil or dirt deposits. Other causes of declines in output power include temporary dust covering all modules, such as sand deposits, and rises in temperature on a module in summer. However, such factors are beyond the scope of this paper, because they do not interfere with the detection of a malfunctioning PV module due to gradual decreases in output power from the entire array of modules.

In the present study, we focus on distinguishing malfunctions from factors (1) and (2) that are observed on a daily basis with our monitoring system.

3.2 Approach to Malfunction Detection

Figure 4 presents graphs for output powers from two modules on the same day. The graph for module #19 indicates the presence of a malfunction, while the graph for #21 indicates that output declines are due to shadow from a utility pole. However, these graphs also demonstrate how it is difficult to distinguish the two reasons just from the graphs alone. Moreover, the objective of this study is to detect as soon as possible malfunctions at their early stages, which is a more difficult challenge.

In order to correctly distinguish between them, our method utilizes correlation information obtained from simultaneously measuring power data from each PV module. More specifically, there are two types of correlation information, relating to spatial and temporal information. The spatial correlation information is obtained by comparing the output power of each module at the same time. In this paper, the spatial correlation information compares output powers from the entire array of modules with each individual module. The temporal correlation information is obtained by plotting a time series graph for output powers for each PV module and by comparing the data in each graph.

By utilizing these two kinds of correlation information, it is possible to distinguish whether a decline is due to some malfunctioning of PV modules or just due to environmental conditions, such as shadow from buildings or trees. The cause is illustrated with the following example.

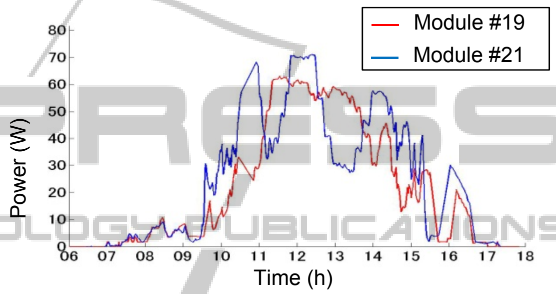

Figure 4: Two examples of output power graphs reflecting different reasons for the power decreases.

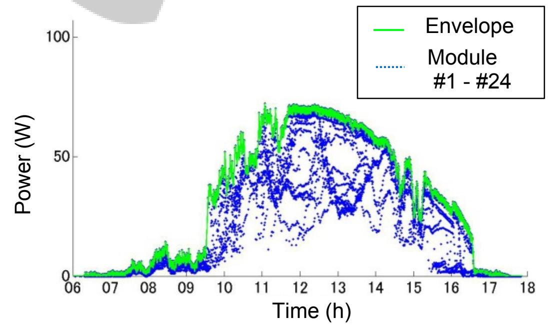

Figure 5: Obtaining a graph of maximum output power.

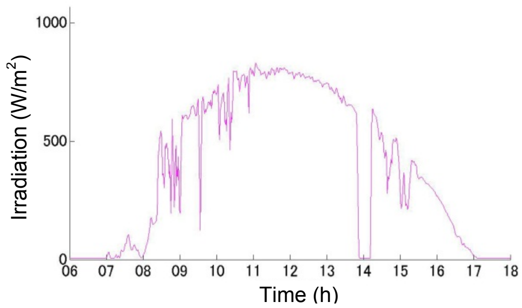

Figure 6: Graph of solar irradiation (same day as Figure 5).

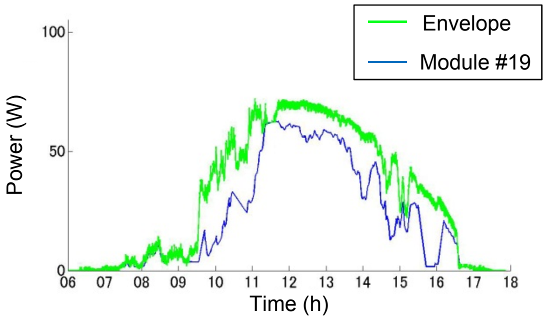

Figure 7: Graph of power output from module #19 and the envelope.

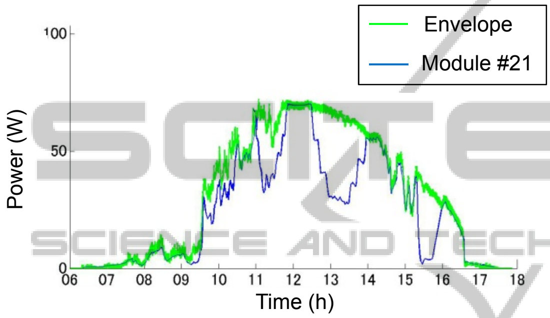

Figure 8: Graph of power output from module #21 with many small shadows and the envelope.

In our method, spatial correlation information is represented as a graph plotting maximum power levels from all the modules, and by comparing this graph with similar power level graphs for each individual module. A graph of maximum power levels is created by superimposing all the graphs for the individual modules over a day, and plotting the envelope, as shown in Figure 5. The shape of the maximum power output represents an approximation of solar irradiation (Figure 6), which can be recognized by comparing the plot shapes in Figures 5 and 6. The graph of the maximum power output is not affected by shadow falling on some of the modules, such as that from a utility pole or a house, because the value is derived from the total area of the complete PV module system.

Thus, the status of any power declines for an individual module can be determined by comparing the temporal graphs for maximum power and for that particular module. The method is illustrated with the example in Figure 4, where the power output declines in the two graphs reflect different causes. When there is a continuous difference between two graphs, as shown in Figure 7, it would indicate a continuous reduction in the power level from an envelope, which would, in turn, indicate some malfunction with the module. In contrast, when two graphs plot similar values over some periods, despite temporal fluctuations between them, as shown in Figure 8, it indicates that the power output fluctuations are due to a shadow passing over the module.

The procedure for calculating this information is outlined in the next section.

4 THE MALFUNCTION DETECTION METHOD

4.1 Overview

The section presents an overview of the malfunction detection method proposed in this paper. First, monitoring data relating to output powers from each module are converted into data adjusting for climate and seasonal changes. In this paper, we call to this conversion “normalization”. The normalized data are converted so that maximum value from all measured output powers from all modules at each measurement time is assigned the value of 1. The normalized data express the output powers relative to all neighbouring modules based on the spatial correlation information. Moreover, the time series graph for each individual module shows the temporal correlation information for each module. Then, malfunction detection is conducted by detecting the modules where the normalized data values are continually at a reduced level.

4.2 Procedure

The method described in the previous section consists of the following three steps. The procedure is easily executed on a PC.

1) Creating maximum output power graphs for all the modules.

First, time series graphs of all the modules for the same day are overlaid. Next, an envelope from the overlaid graphs is plotted (Figure 5). This envelope represents the maximum output power graph for all the modules.

2) Creating the normalized data.

The measured output powers are normalized so that the total value of the envelope, representing the maximum value, is always assigned a value of 1. The normalized values are obtained by dividing each output power by the envelope values for the corresponding time point. The normalized value represents an output power that is not influenced by changes in solar irradiation due to seasonal or weather conditions. Thus, the modules that have normalized values that are continuously lower than a certain value can be detected as possibly malfunctioning. An example of normalization is presented in the next section.

3) Detecting modules with continuously reduced normalized values.

Modules for which the normalized value is continuously lower than 1 are detected as malfunctioning. The method of detecting malfunctioning modules is to plot a graph for each module for the daily maximum normalized values, and if a value is lower than some threshold level, that would be detected.

Results from a detection experiment using this method are presented in the next section.

5 EXPERIMENT SIMULATING MALFUNCTION DETECTION

To confirm the effectiveness of the malfunction detection method, we conducted an experiment that simulated malfunction detection with actual data from our PV module monitoring system. The experiment used Showa-Shell CIS thin film 24 PV modules that are installed within the monitoring system. The goal of the experiment is to simulate a malfunction by covering 10% of module #19 (Figure 9) and to detect the period of the simulated malfunction. The power output from the covered module decreased only by about 15%, so successful detection of such a decline would indicate that the method is capable of detecting malfunctions in the early stages of malfunctioning.

Figure 7 shown in Section 3 presents a graph for the power output from the 10% covered module #19. The data are converted into normalized power values for easier comparison of power reductions, as described in Subsection 4.2. Figure 10 presents a graph of the normalized power values converted from the data in Figure 7. Graphs for normalized power are made for all the modules on the days monitored.

Figure 11 presents the maximum normalized power output for one day during August 2012 from the 10% covered module #19, and from module #21 which is a neighbouring module that is representative of the normal modules. The maximum normalized values on the graph are calculated from the daily data for the interval from 1 pm to 5 pm, because there is relatively little shadow during that interval.

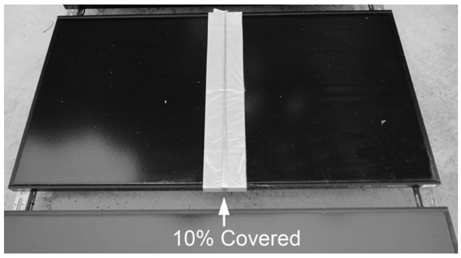

Figure 9: PV module #19 with covering of 10% total area.

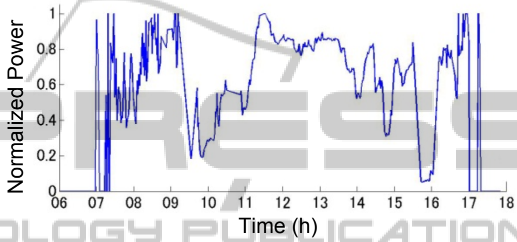

Figure 10: Graph of the normalized power values for module #19.

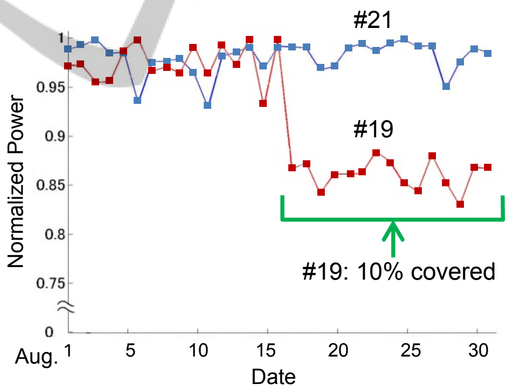

Figure 11: Experimental result.

Ten percent of the surface of module #19 was continuously covered from August 16, and that resulted in a continuous reduction in the level of power output. Figure 11 shows that the maximum normalized values were close to 1 prior to partial coverage, but that once the cover was in place, the maximum normalized values decreased to approximately 0.85. This graph clearly indicates that the level of power output from this module was lower from the start of the experiment, and that this simulated malfunction can be detected by setting a detection threshold of 0.9 for the maximum normalized power. This result confirms that our method is capable of detecting an individual PV module with a loss of approximately 15% in power output. This result also shows that a module where the level of power outputs begins to decline can be detected as potentially malfunctioning.

6 DISCUSSION

In this experiment, we only utilized the spatial correlation information in comparing the power output with the maximum power for the entire modules and the power levels for each individual module. However, there are various kinds of spatial correlation information, such as correlations between neighbouring module groups or between individual modules. In particular, modules within the same string tend to be highly correlated because they mutually influence voltages within the same current. The attainment of better malfunction-detection performance by utilizing more complex forms of spatial correlation information will be tackled in future research.

The present experiment focused on a malfunction where the level of power output suddenly decreases, but there are other forms of malfunctioning, such as gradual decreases in output power. In those situations, it is not possible to detect the malfunction until a certain level of decrease is reached. But once it has been reached, our method can detect such malfunctions.

In the present paper, we have focused only on power, which is the representative value of output within the solar energy data. However, we may expect even faster and more accurate malfunction detection performance by using other values, such as voltage, current, and temperature. We will continue to consider the utilization of such values for the detection of malfunctioning PV modules.

Our method can be applied to mega-scale solar systems by changing the unit of measurement from the single module to a string of modules. In the future, we are planning to apply the method to a mega-scale solar system.

7 CONCLUSIONS

In this study, we have developed a method of malfunction detection using a monitoring system of the individual PV modules. The method makes it possible to detect malfunctions in their early stages in terms of slight declines in the levels of power output from a PV module, which it has been very difficult to be aware of previously. We confirmed the effectiveness of the method through a detection experiment for a simulated malfunction using actual data from our monitoring system for individual PV modules. In the future, we plan to explore the application of our method to mega-scale solar systems.

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REFERENCES

Tan, D. and Seng A. K., 2011. *Handbook for solar photovoltaic (PV) systems*, Energy Market Authority.

Chouder, A. and Silvestre, S., 2010. Automatic supervision and fault detection of PV systems based on power losses analysis. In *Energy Conversion and Management*, 51, pp. 1929-1937, Elsevier.

Polo, F. A. O., del Rosario, J. J. A. and Garcia, G. C., 2010. Supervisory control and automatic failure detection in grid-connected photovoltaic systems. In *N. Garcia-Pedrajas et al. (Eds.): IEA/AIE 2010*, Part I, LNAI 6096, pp. 458-467, Springer.

Stettler, S., Toggweiler, P. and Remund, J., 2006. SPYCE: satellite photovoltaic yield control and evaluation. In *21st European Photovoltaic Solar Energy Conference*, pp. 2613-2616.

Phoenix Contact GmbH & Co. KG, 2012. *String monitoring in photovoltaic systems*, [online] Available: http://www.phoenixcontact.com/global/signal-level-matching/242_66017.htm.

Onamba Co., Ltd., 2010. *Photovoltaic intelligent monitoring system* (in Japanese). [online] Available: http://www.onamba.co.jp/pdf/monitor_catalog.pdf.

Tigo Energy, Inc., 2009. *Tigo Energy MaxiManager software data sheet*. [online] Available: http://www.tigoenergy.com/sites/default/files/attachments/software.pdf.

Nosato, H., Kasai, Y., Takahashi, E. and Murakawa, M., 2012. A very low-cost low-ffrequency PLC system based on DS-CDMA for DC power lines. In *16th IEEE International Symposium on Power Line Communications and Its Applications (ISPLC2012)*. pp. 398-403, IEEE.

Nosato, H., Kasai, Y., Iwata, M., Takahashi, E. and Murakawa, M., 2013. The development of the individual photovoltaic module monitoring system using power line communication. In *The Transactions of the Institute of Electronics, Information and Communication Engineers* (in Japanese), J96-D (3) (in press), IEICE.