AI-based Diagnostic System for Utility-Scale Solar Power Plants

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To ensure the stable operation of utility-scale solar power plants over a long period, it is necessary to improve the inspection and maintenance levels, especially the inspection efficiency of the DC voltage parts, for which visual inspection has been conducted. Sumitomo Electric Industries, Ltd. has developed a system that detects abnormalities in solar panels by analyzing string data with AI. Data on detected abnormalities, including their types and urgency, are reported to the power plant manager via daily emails and used for efficient facility maintenance. Using the system, we also provide diagnostic services suggesting best inspection methods and countermeasures for the abnormalities.

Keywords: power line communication (PLC), utility-scale solar, string monitoring, abnormality detection, diagnosis service

1. Introduction

In Japan, after the feed-in tariff system was phased in from 2009, diverse business operators started to construct utility-scale solar power plants. By the end of 2019, the ratio of solar power generation to Japan's total power source structure had increased to 7%.(1)

On the other hand, operators have a different degree of concern regarding the maintenance of their power plants. For DC voltage parts, particularly, licensed electrical engineers are entrusted with the task of drawing up maintenance menus regarding what should be checked to what extent. Visual inspection of DC voltage parts, which is currently a mainstream, has a major problem that needs to be resolved in order to ensure long-term stable operation of power plants.

Given the background described above, we have commercialized a string monitoring system (SSMAP) that can thoroughly monitor the amount of power generated by DC voltage parts.(2) This new system is equipped with a power line communication (PLC) that collects the data on the power measured in each string. Together with the monitoring data on pyranometers, thermometers, photovoltaic (PV) inverters, and other devices, the data collected by the PLC are aggregated into the core monitoring system (host system) of a specialized manufacturer and visualized.

However, some operation and maintenance operators in charge of practical power plant maintenance cannot efficiently utilize the visualized numerical values and graphs to detect abnormal incidents occurring at the power plant because they lack expertise in such incidents. Although some host systems are provided with an abnormal data detecting/reporting function, the problem is that they use a threshold to detect an abnormality. Since each power plant is operating in a different environment, false abnormality detections and subsequent alarms will frequently occur if a single threshold is used commonly for abnormality detections.

In order to break through the above situation, we participated in the 2017 Maintenance Regulations Sophistication Project for New Energy—Evaluation and Verification of Electrical Facility Maintenance Technology Sophistication, which was launched and managed by the Ministry of Economy, Trade and Industry in Japan. Using the abnormality detection technology that we cultivated in the project as a base, we developed and commercialized an original abnormality detection system that analyzes string data with artificial intelligence (AI). Using this new system, we started offering abnormality diagnosis services that inform our customers of the abnormality inspection details and effective abnormality countermeasures. This paper describes the features of the new abnormality detection technology and typical examples of the abnormality diagnosis service that uses this technology.

2. Outline and Features of Abnormality Diagnosis System

2-1 String data collected by PLC system

The configuration of a string monitoring system installed in a utility-scale solar power plant is shown in Fig. 1.

At the utility-scale solar power plant, strings of PV modules connected in series are collected in a combiner box and then connected to the PV inverter. The power generated by the strings is converted into alternating

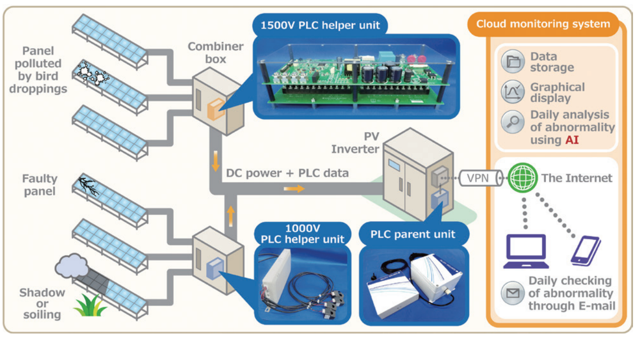

Fig. 1. String monitoring system configuration

current by the PV inverter and is interconnected to the power grid.

The string monitoring terminal, which is installed in the combiner box, measures each string current and voltage. A PLC system that uses DC cables as communication lines transmits the measured data to the data collection device installed in the PV inverter input section.

The use of the PLC system eliminates the need for laying a dedicated communication line and makes it easy to install the string monitoring system in an already operating power station. Furthermore, the non-use of a communication line makes the monitoring system less susceptible to induced lightning and thus increases the lightning resistance. To date, the monitoring system has been used in 70 power plants, but no case on lightning damage has been reported.

2-2 Abnormality diagnosis using string data

String data aggregated into the data collector are stored in the data storage/analysis device built on the cloud and used to diagnose the abnormality of the utility-scale solar power plant.

Since the number of strings per megawatt is approximately 200 to 300, visually detecting an abnormality is difficult.

We originally built a system that classifies string abnormalities into seven types as shown in Fig. 2 and sends the classification result to the power plant manager via daily e-mails. This system is based on our unique technology that diagnoses abnormalities using AI, as described later. The new system enables the plant manager to daily understand the type and urgency of the abnormality without using a particular skill and conduct a timely, efficient maintenance.

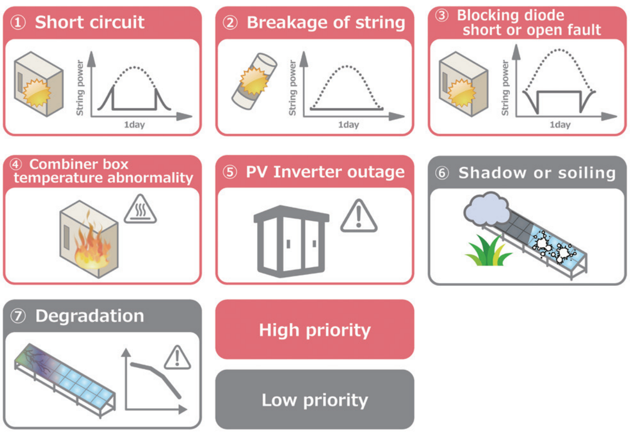

Fig. 2. Classification of string abnormalities

3. Development of Power Generation Abnormality Diagnosis Technology

3-1 Abnormal incidents to be diagnosed

PV modules and DC devices (such as blocking diodes, wiring, circuit breakers, connectors, and terminal blocks) used in a solar power plant were analyzed using the fault tree analysis (FTA) technique to determine the factors that degrade the amount of power generated by the plant. The analysis results are shown in Fig. 3. We studied to elucidate how each factor would reduce the power generation output and also visited our customers to know the incidents they were in trouble. Using the study and interview results as a reference, we developed a technique for detecting seven types of abnormalities according to string voltage/current data as shown in Fig. 2. Abnormal incidents generally cause changes in the amount of power generation according to the three patterns shown in Fig. 4. The method for detecting an abnormality following each pattern is described below using a typical abnormality as an example.

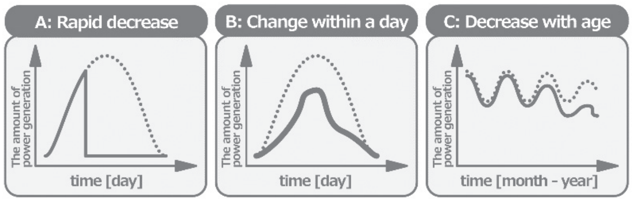

Fig. 4. Change patterns defined for the amount of power generation

3-2 Short-circuit fault detection for blocking diode

To detect a sharp decrease in the amount of power generation, it is effective to monitor the data measured at a short cycle. The new string abnormality diagnosis system analyzes the instantaneous values measured at a sampling cycle of 6 s by averaging them every 1 min. For the short circuit fault analysis of blocking diodes, we focused on the time period when the solar radiation intensity is low in the morning and evening since the amount of power generation does not significantly change during the daytime. The solar radiation intensity in the morning and evening is as small as approximately 100 W/m^2, but the PV modules continue to generate power. The string monitoring terminal operates on this small amount of power generated, but the PV inverter stops because it cannot acquire the amount of power necessary for the operation. In a trouble-free power plant, the route for flowing the power generated by the PV modules is not constructed when the PV inverter is stopped. Therefore, the amount of power generated during this time period is 0. However, if the blocking diode causes a short circuit fault and reduces the open circuit voltage of the string, a current will flow into the string from the surrounding PV modules, causing a reverse current to flow through the string. An example of current change in a string under conditions that the blocking diode breaks down due to short circuit and that a shadow on a panel reduces the open voltage of the string is shown in Fig. 5. It can be seen from this figure that a reverse current occurs while the PV inverter stops for 0 to 3 s.[3] The new string abnormality diagnosis system accurately identifies the short circuit fault of the blocking diode by monitoring this abnormal current. Detecting the short circuit fault of blocking diodes has been extremely difficult until today.

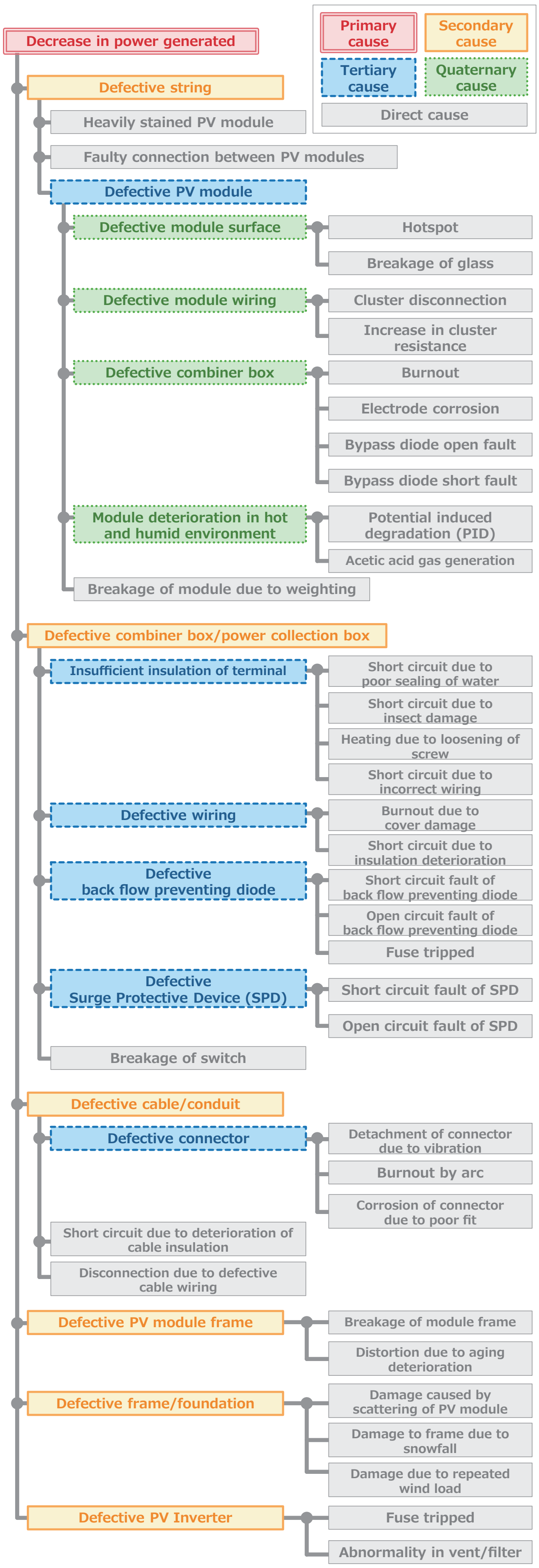

Fig. 3. FTA analysis results for the cause of decrease in power generation output

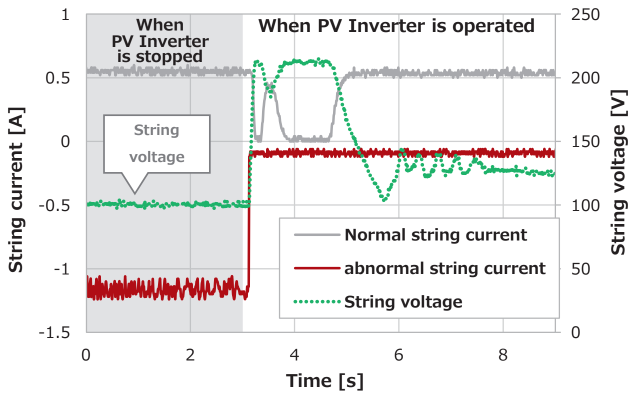

Fig. 5. Change in string current when blocking diode breaks down due to short circuit

3-3 Detection of power generation output decrease due to shadow

In order to understand the time period variation pattern of the amount of daily power generation, it is efficient to correctly understand the feature of the waveform of the power generated and classify an enormous quantity of data on power generation by trend. For abnormal incidents in which the amount of power generation changes complexly depending on time period, the new string abnormality diagnosis system uses the clustering algorithm,(4) an unsupervised learning technique, to classify the waveforms based on their feature. The accuracy of the classification results is nearly equal to that of the waveform examination results obtained by engineers. Given that the change in the amount of power generation due to shadow depends on the movement of the sun, the effect of a shadow on power generation differs between time periods. As the analysis target data, the new string abnormality diagnosis system uses the 1 h average value of the power generated during approximately 12 h from sunrise time to sunset time to remove the short-term fluctuation component due to the variation of solar radiation fluctuation. As shown in Fig. 6,

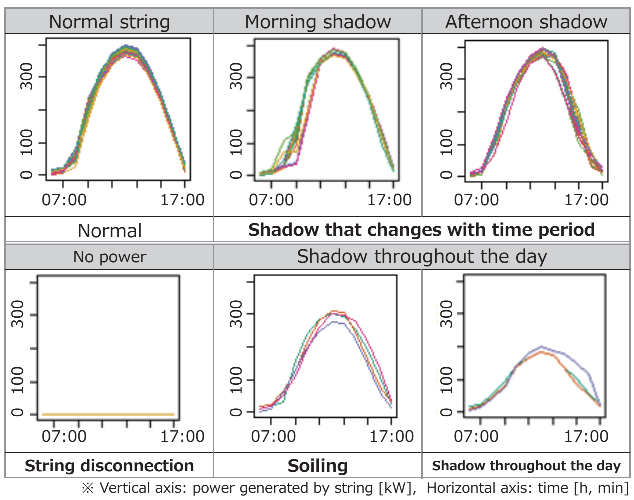

Fig. 6. Example of abnormal waveform detected by clustering algorithm

application of the clustering algorithm makes it possible to automatically classify the data based on the feature of the waveform of the power generated. In order to evaluate the performance of non-defective strings, the power generation time period is divided into three categories, namely, morning, daytime, and evening, and an abnormal group of strings such as those affected by morning shadows is detected based on a decrease in the amount of power generation in each time period.

As a result of a field investigation of the strings that were diagnosed to have been shadowed, the cause of each shadow was clarified, as shown in Fig. 7. For strings shadowed by weeds, removing the cause will reduce the power selling loss. In this way, the new string abnormality diagnosis system detects abnormal incidents that change the amount of power generation with time period.

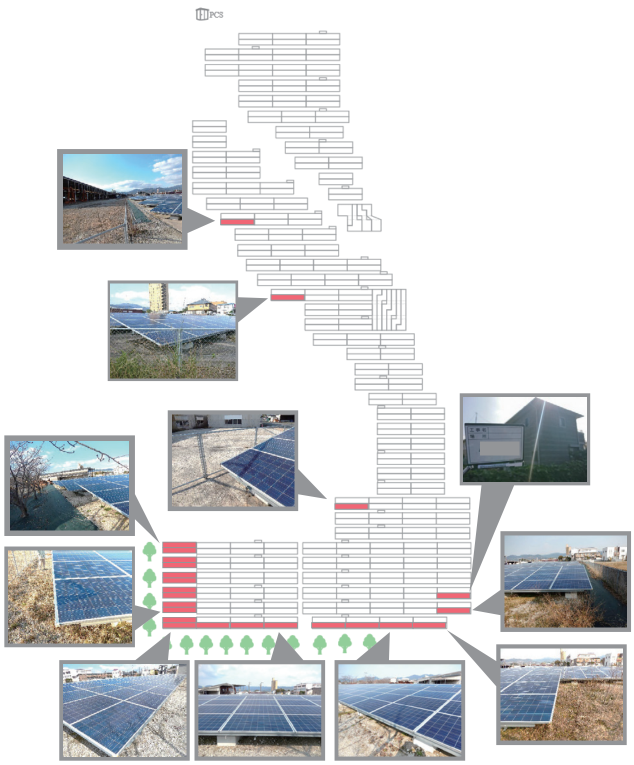

Fig. 7. Field investigation example for strings on which a shadow was detected

3-4 Detection of decrease in the amount of power generation due to aging deterioration

In order to understand the pattern of decrease in the amount of power generation due to aging, it is efficient to classify yearly long-term data by their trend. In the example shown in Fig. 8, the feature points are extracted from the generated power waveform, which significantly varies day by day, then the performance diagnostic waveform is generated using the future points. The performance diagnostic waveform obtained by the above normalization is used to diagnose strings that cannot achieve an annual deterioration rate of less than 1%, a value generally guaranteed for solar panels. However, some strings are practically difficult to diagnose in terms of aging deterioration because of seasonal shadows. The new string abnormality diagnosis system identifies the aging deterioration of these strings after eliminating the influence of seasonal shadows.

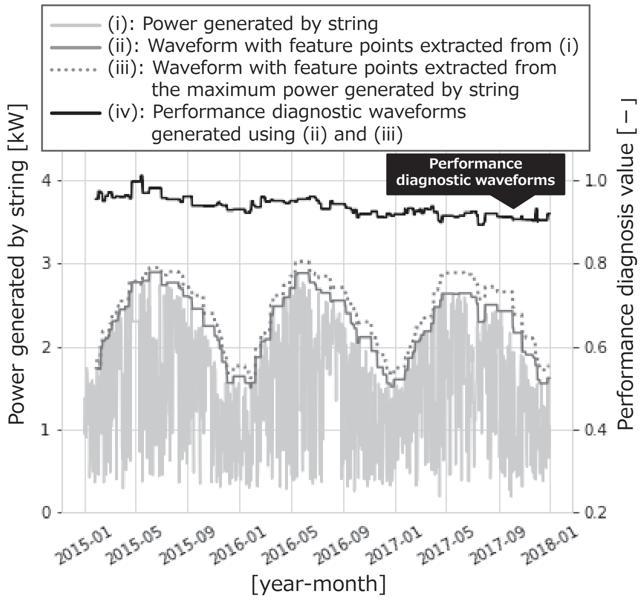

Fig. 8. Example of performance diagnosis

4. Examples of Abnormality Diagnosis Service and Power Selling Loss Reduction

In the automatic diagnosis of abnormalities by the new string abnormality diagnosis system and the daily power generation report e-mail shown in Fig. 9, the daily power generation status and abnormality diagnosis results are notified. Timely implementation of cost-effective abnormality prevention measures after correctly understanding the trend of abnormal status will help further save maintenance labor and enhance the efficiency in power plant maintenance.

At the end of November 2019, we started to provide our customers with a power plant analysis report service to assist them in labor saving and efficiency enhancement. In this service, we thoroughly analyze the customers' power plants to inform them of abnormal status change from the previous year and propose a cost-effective abnormality countermeasure plan besides daily report e-mails.

4-1 Description of abnormality diagnosis service

Through this service, the operational status of a specific power plant can then be evaluated by analyzing the histograms of various power plant data that we have already collected. In the example shown in Fig. 10, the amount of power generated by the strings in customer's power plant A varies widely, verifying that many of them are not operated in an ideal power generation environment. The low histogram peaks and wide variance of the amount of power generated are due to the spread of weed shadows and inadequate regular maintenance such as module cleaning. The histogram has two peaks, suggesting that many strings are affected by shadows and they are not also regularly maintained. We are ready to propose a highly cost-effective maintenance plan on the basis of the abnormality analysis results described above.

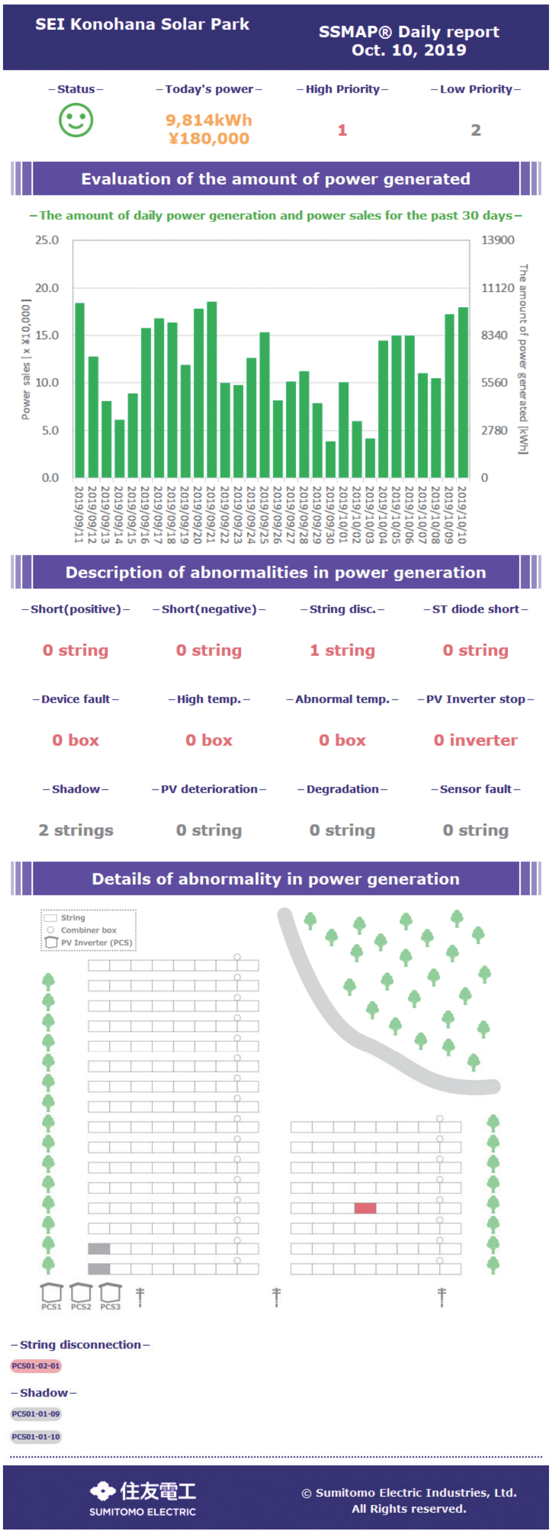

Fig. 9. Example of daily report e-mails

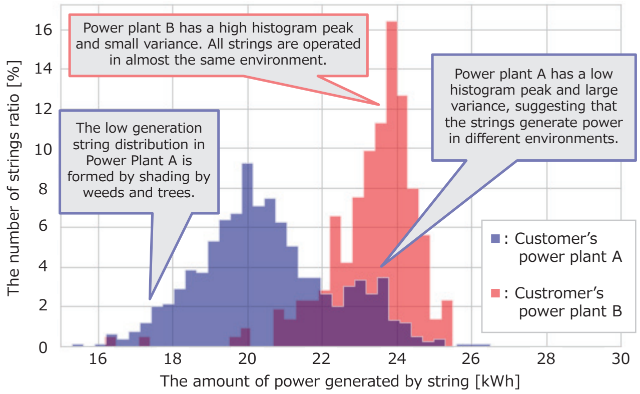

Fig. 10. Comparison example of actual power generation using histogram

4-2 An example of power selling loss reduction scheme when elimination of shadow is difficult

The results of field investigation of a power plant revealed that the plant had been affected by the shadow of a fence. We proposed the plant to replace the wiring as shown in Fig. 11. The plant adopted the proposal and actually increased the power sales. Since eliminating the shadow in this example was challenging, we suggested the plant to reduce the number of strings affected by the shadow. In practice, we renovated the plant after simulating the effect of our proposition on an increase in power sales. Consequently, the plant achieved a 2.3% increase in the amount of power generation. The cost of rewiring associated with the reduction of the number of strings affected by the shadow can be recovered in nearly 8 years. Additionally, the renovated plant is expected to increase the total power sales after a remaining operation period of 15 years.

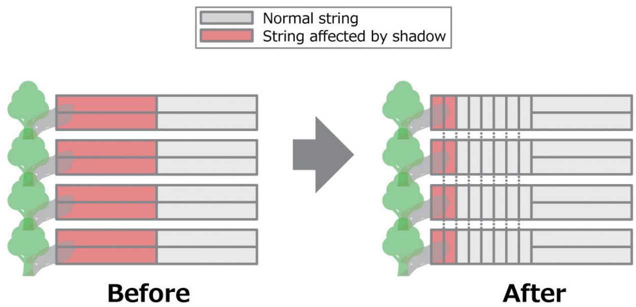

Fig. 11. Example of proposal on string rewiring work

5. Conclusions

Abnormality diagnosis technology for solar power generation facilities is necessary for ensuring their stable operation over a long period and coping with maintenance personnel shortage in the future. We will further enhance the accuracy of the abnormality detection technology, which is a continuous remote monitoring technology using a string monitoring system, to sophisticate our string diagnosis services and save on-site maintenance labor.

• SSMAP is a trademark or registered trademark of Sumitomo Electric Industries, Ltd.

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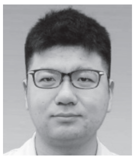

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