Featured Articles

O&M Service for Megasolar Power Plants and Precise Monitoring Techniques for PV Modules

Tohru Kohno
Tetsuharu Ohya
Tomoharu Nakamura

OVERVIEW: The success or failure of large ("megasolar") PV power generation businesses depends on their ability to perform reliably over a period of 20 years. However, the short history of the megasolar power business itself means there is a lack of data and know-how relating to long-term reliability and maintenance. Hitachi is putting a lot of effort into long-term, turnkey services that handle plant O&M on the owner's behalf. In addition to its experience with the maintenance of electrical conversion and distribution equipment, Hitachi also supplies cloud-based remote monitoring services that utilize its IT infrastructure. PV modules are a key component of these power plants, and Hitachi also utilizes its own proprietary techniques for the precise detection of faults or degradation in these modules.

INTRODUCTION

THE construction of photovoltaic (PV) power plants has been growing dramatically since the introduction of a feed-in tariff scheme for renewable energy in July 2012. Whereas the total installed capacity prior to the scheme's introduction was approximately 5,600 MW, this had grown to approximately 11,260 MW by October 2013, more than doubling in a period of little more than a year. With further large-capacity plants still to commence production, this trend appears set to accelerate.

Whereas approximately 80% of PV power generation in the past was for household use, commercial plants have made up about 70% of the capacity since the introduction of the feed-in tariff scheme. The key considerations for commercial applications are the long-term reliability of the power plant and sustaining steady operation without ignoring faults or performance degradation.

In response, Hitachi is putting a lot of effort into operation and maintenance (O&M) services that help maintain consistent operation over the long term. PV modules are a key component of these power plants, and Hitachi has developed its own technology for monitoring these modules for faults or degradation through a cloud service.

This article describes these O&M services for megasolar power plants and precise monitoring techniques for PV modules.

O&M SERVICE OVERVIEW AND SYSTEM

It is common practice with PV power generation for the plant to be managed by a specific-purpose company (SPC) set up by the company behind the project. When this structure is adopted, the SPC tends to be small and often finds it difficult to establish the resources needed for O&M. This is exacerbated by a lack of O&M know-how resulting from the fact that the industry is so young. For situations like this, Hitachi offers a turnkey service that can handle equipment O&M on the operator's behalf. In providing this turnkey service, Hitachi can draw on the monitoring techniques and know-how described below to achieve consistent operation over the long term.

Causes of Faults on Megasolar Power Plants

Megasolar power plants include PV modules, power conditioning systems (PCSs), transformers, junction boxes, and distribution boards. Faults can arise at various points in these plants, such as in the electric power distribution equipment, power electronics, or PV modules. In particular, because the PV modules are situated outdoors where they are exposed to the sun, wind, and rain, they are likely to be subject to phenomena that can cause reductions in their output due to deterioration over time. External factors include the surface of the modules becoming dirty due to dust or other material carried in the air, the droppings of crows and other wildlife, or glass breakage due to

TABLE 1. O&M Services
Hitachi offers extensive support for the operation and maintenance of megasolar power plants.

Service	Description
Operational support	• 24-hour remote monitoring • Operating data management, analysis of operation (comparison with targets, etc.) • Reporting (daily, monthly, and annual reports)
Routine operation support	• Routine inspections (weekly or monthly, etc.)
Maintenance inspections	• Maintenance planning • Routine inspections, planned part replacements • Faults, repair of worn parts
Emergency response	• Initial response • Fault recovery
Ancillary services	• Online monitoring of PV module degradation or faults • Web site design

PV: photovoltaic O&M: operation and maintenance

falling rocks (which is also assumed to be the work of crows). Rather than a standard range of services, it is important that O&M offer services that are capable of handling potential problems like these.

Available Services

Inspection and Maintenance Service

Table 1 lists the O&M services offered by Hitachi. Routine operation support (routine on-site inspection) is based primarily around visual inspections to check for things like broken or bent equipment, corrosion, staining, or rust. Inspection and maintenance consists of conducting periodic inspections and replacing parts as required to ensure that equipment functionality is maintained. The service ensures electrical integrity (insulation resistance measurement, and operation checks on PCSs, transformers, monitoring systems, and other equipment), as well as the replacement of consumables (fuses, space heaters, filters, packing, etc.).

Remote Monitoring Service

The operation of PV power plants is typically automated and unattended. Consequently, if a problem does occur, it may take a long time for it to be identified, resulting in a loss of long-term generation output and risking it developing into a more serious fault. To deal with this, Hitachi offers a remote monitoring service. The service performs 24-hour remote monitoring of the customer's generation plant operation from a control center so that it can respond promptly when a problem occurs, including notifying the customer by telephone or e-mail and dispatching a technician to the site if necessary. The remote monitoring system provides a way for relevant company departments, which may be based at different sites, to obtain detailed information about the power plant. Hitachi also supplies a range of services that reduce the workload of the power plant operator, including the management of operational data and analysis of plant operation.

This remote monitoring service utilizes Hitachi's information technology (IT) infrastructure to provide a highly reliable service that encompasses information security.

MONITORING FOR PV MODULE DEGRADATION OR FAULTS

Degradation and Fault Modes

PV cells are the main components in PV modules. However, these cells are not the only cause of degradation and faults in PV modules, with degradation of the cell connection wiring and filler material used in module construction also being major factors. The cells are connected together by metal wires (interconnectors) that are soldered to the cells. Also, the junction boxes are fitted with bypass diodes (see Fig. 1).

Because degradation or faults in these components are reflected in the equivalent circuit parameters of the PV cells, they can be identified quantitatively. Degradation or other component faults can be categorized into a number of different fault modes (solder peeling, cell degradation, broken wires, loss of optical transparency), each of which influences equivalent circuit parameters (series resistance, shunt resistance, bypass diode operation, and PV current) in different ways (see Fig. 2).

Diagnostic Techniques

The power generation level is monitored to identify performance degradation or other faults in PV modules.

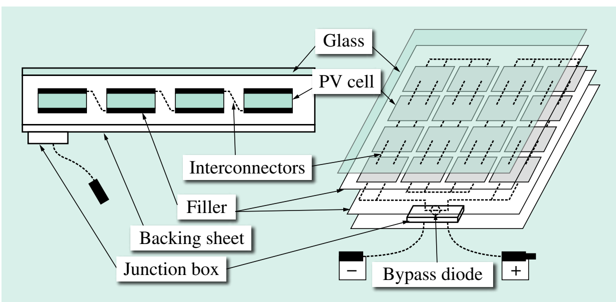


Fig. 1—Cross-section of PV Module.
The PV cells are not the only source of PV module degradation and faults. Degradation of filler material and interconnectors are also common causes.

Fault mode	Cause	Effect on equivalent circuit
Solder peeling	• Increased resistance in interconnector wiring	Increase in series resistance (Rs)
Cell degradation	• Deterioration in performance of PV cell • Development of ohmic characteristics	Drop in shunt resistance (Rsh)
Broken wire	• If the performance deterioration is large, the bypass diode will operate continuously	Bypass diode on
Deterioration in optical transparency	• Dirty glass • Peeling of filler	Drop in photovoltaic current (I_{sc0})

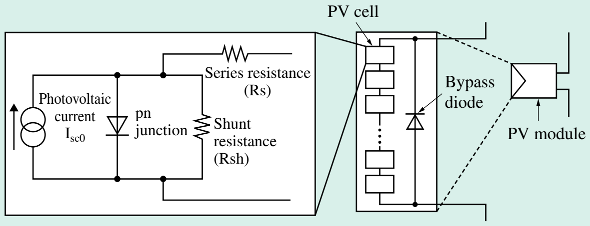
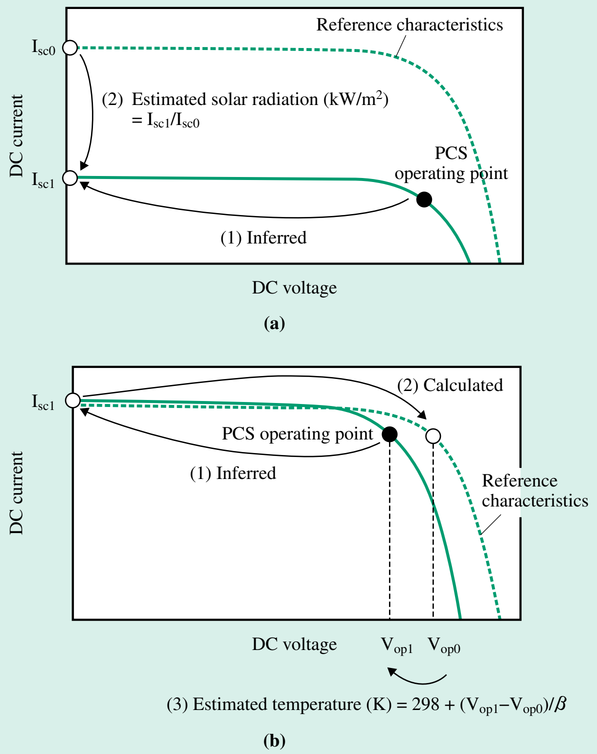


Fig. 2—Fault Modes and Equivalent Circuit.
PV module faults can be classified into a number of different fault modes and characterized in terms of equivalent circuit parameters with high accuracy.



DC: direct current PCS: power conditioning system

Fig. 3—Calculation of Estimates for Solar Radiation (a) and Temperature (b).
The level of solar radiation at the PV cells (estimated solar radiation) and the PV cell operating temperature (estimated temperature) are calculated from the PCS operating point (DC voltage and current).

While the conventional technique is to monitor the power output and compare it with solar radiation, because factors such as the air temperature and level of solar radiation fluctuate, and may vary across a large site, it is difficult to identify degradation or other faults until the fall in output reaches a certain level.

Hitachi has developed a monitoring method that assesses the state of the PV modules with a high degree of accuracy by obtaining more accurate values for the solar radiation (estimated solar radiation) and temperature (estimated temperature) from the actual operating point. Next, it calculates the theoretical power output based on these estimates and the equivalent circuit parameters, and then compares this result with the actual output(1)(2).

The key technique in this method is that, instead of utilizing the raw measurements from pyrheliometers and thermometers, it uses theoretical values for solar radiation (estimated solar radiation) and module temperature (estimated temperature) calculated from the PV module characteristics and measured values (see Fig. 3). This eliminates both the need to rely on an uncertain measurement from a pyrheliometer positioned at a representative location and also the need to estimate the module temperature from the air temperature.

PV module diagnostics compares the measured current with the theoretical current calculated from the above estimated solar radiation and temperature and the measured operating voltage. A difference between these two current values indicates whether the PV module has a fault or suffers from performance degradation. The diagnostic procedure then performs an iterative calculation, recalculating the current for different numbers of PV module faults until the estimated and measured currents converge. This provides an estimate of the number of PV module faults. If string monitors are used, the monitoring function incorporates the fault mode into the calculation to determine which mode gives the best agreement with the actual string current (see Fig. 4).

The procedure was tested on a 50-kW system installed at Hitachi's Central Research Laboratory. Corrugated plastic was placed over the PV modules to simulate a fault (see Fig. 5). When 32 sheets of corrugated plastic were used, the procedure estimated the number of faults at 33, thus confirming that losses of around 2 to 3% can be detected (see Table 2). A similar result was obtained from another test using

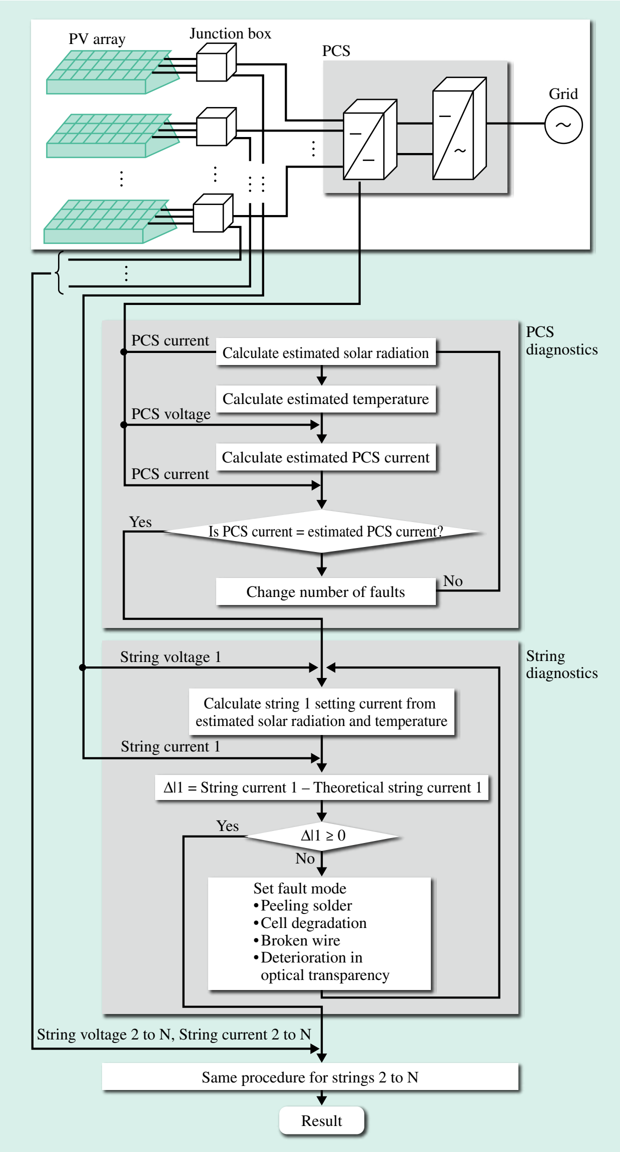


Fig. 4—Diagnostic Flowchart.
This performs an iterative procedure that determines the fault mode by calculating the solar radiation and temperature from the PCS voltage and current until the theoretical estimated current and measured current converge.

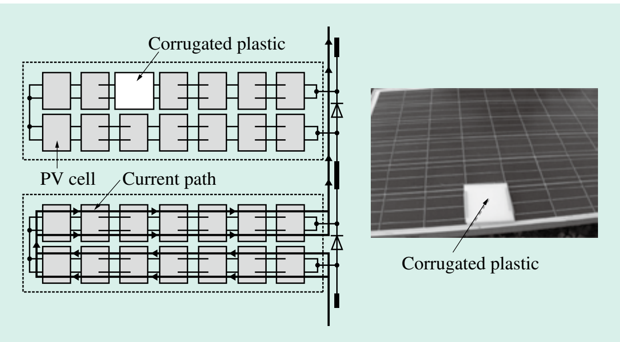


Fig. 5—Use of Corrugated Plastic to Simulate Fault.
Corrugated plastic was placed over a PV module to simulate a broken wire fault by forcing the current to flow through the bypass diode.

TABLE 2. Results of Testing on 50-kW System (PCS Diagnostics)
When 32 faults were simulated (using corrugated plastic), the procedure estimated the number of module faults at 33 using only the DC voltage and current of the PCS.

Test	PCS diagnostics					
	Estimated power	Actual power	Estimated temperature	Estimated solar radiation	Degradation	No. of module faults
32 sheets of corrugated plastic	36.4 kW	36.3 kW	60.7°C	0.83 kW/m^2	2.34%	33

TABLE 3. Results of Testing on 50-kW System (String Diagnostics)
Even for a loss of only 2 to 3%, the fault mode could be identified using the DC voltage and current from the string monitor.

Test	String diagnostics result				Result
	Estimated power	Actual power	Estimated temperature	Estimated solar radiation	
Covered with corrugated plastic	1.965 kW	1.899 kW	43.7°C	0.67 kW/m^2	Broken wire
Inserted 1.3Ω resistor	2.511 kW	2.468 kW	53.7°C	0.88 kW/m^2	Solder peeling

string diagnostics in which two different faults were simulated (respectively, insertion of a 1.3Ω resistor in the wiring and placement of corrugated plastic over the module) (see Table 3).

Cloud-based Services

Information on plant operation can be collected via a network from the PCSs. Hitachi has built a system that transmits the direct current (DC) voltages, DC currents, pyrheliometer measurements, and air temperature measurements from the PCSs to a monitoring server at a Hitachi data center, where diagnostics are performed and the results stored (see Fig. 6). This makes possible a variety of additional services.

For example, Hitachi has added a function for analyzing how the extent of degradation varies over time in order to determine when an on-site inspection is needed. Because Hitachi has a technique for accurately reproducing current-voltage characteristics in the presence of degradation or faults, it can provide comprehensive services that include using this technique to localize faulty modules.

By improving the flexibility of the diagnostic functions in the monitoring server, Hitachi can provide an accurate monitoring service that supports long-term operation. For example, while the replacement of modules over a long operating life will likely result

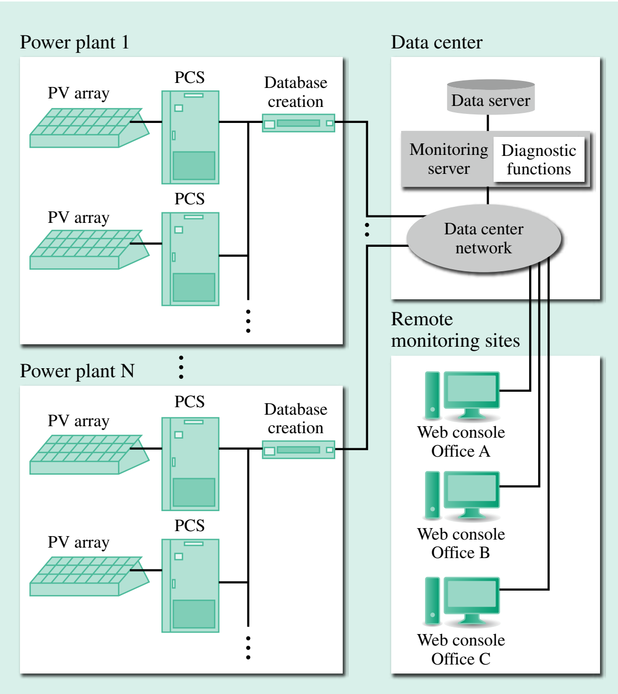


Fig. 6—Cloud-based Implementation of Diagnostic Functions.
Additional services are provided by collecting diagnostic results obtained from diagnostic, time-series, and other data from a number of sites.

in different types of PV modules coexisting, Hitachi's system can still provide accurate monitoring at such sites by updating the monitoring server with details of the added modules.

Hitachi is also developing a service that will determine the best time to replace modules based on the predicted losses in 15 or 20 years' time, which will be obtained by using the cloud to collate information such as the extent to which degradation has changed over time and the results of accelerated indoor testing conducted by Hitachi.

CONCLUSIONS

Japan is entering a new era in which large amounts of PV power will be generated. However, the shortage of experience with full-scale power plants means there is a need to establish technologies for supporting reliable operation over the long term. The fault monitoring techniques described in this article are one example. Hitachi anticipates that combining these fault monitoring techniques with techniques for verifying long-term reliability will help establish PV power generation as a viable business.

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ABOUT THE AUTHORS

Tohru Kohno
Energy Conversion Electronics Research Development, Central Research Laboratory, Hitachi, Ltd. He is currently engaged in research and development of a large-scale photovoltaic power generation system.

Tetsuharu Ohya
Photovoltaic Power Generation Systems Department, Hitachi Works,Power Systems Company, Hitachi, Ltd. He is currently engaged in design of photovoltaic power generation systems.

Tomoharu Nakamura
New Energy Division, Power & Industrial Systems Division, Power Systems Company, Hitachi, Ltd. He is currently engaged in development of a large-scale photovoltaic power generation system. Mr. Nakamura is a member of the Institute of Electrical Engineers of Japan (IEEJ) and the IEEE.