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Solar Energy Materials & Solar Cells 75 (2003) 655–663

Solar Energy Materials & Solar Cells

www.elsevier.com/locate/solmat

Diagnostic technology and an expert system for photovoltaic systems using the learning method

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Abstract

Diagnostic technology for photovoltaic (PV) systems was developed, using the learning method to take each site's conditions into account. This technology employs diagnostic criteria databases to analyze data acquired from the PV systems. These criteria are updated monthly for each site using analyzed data. To check the shadows on the PV modules and pyranometer, the sophisticated verification method was also applied to this technology. After the diagnosis, a basket method provides maintenance advice for the PV systems. Based on the results of precise diagnoses, this expert system offers quick and proper maintenance advice within a few minutes. This technology is highly useful, because it greatly simplifies the servicing and maintenance of PV systems.

Keywords: Learning method; Diagnostic technology; Criteria; Expert system; Photovoltaic system; System performance ratio; Inverter conversion efficiency; Maintenance

1. Introduction

The use of photovoltaic (PV) systems is now increasing rapidly all over the world. With this increase in PV systems, the number of problems cannot be considered negligible even though PV systems are thought to offer a low fault ratio and long mean time between failures. The importance of service and maintenance is therefore growing. However, it is difficult and takes a long time to identify the cause of

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PII: S0927-0248(02)00149-6

problems in PV systems. This is due to the many complex factors involved, such as temperature, irradiation, shadows, etc., which influence PV system's performance.

We developed a diagnostic technology for PV systems based on our statistically analyzed data. And taking each site's conditions into account, the diagnostic technology uses the learning method. According to precise diagnoses, an expert system based on our maintenance experiences database was also added for providing maintenance advice such as "The pyranometer is broken down. Please check or replace it".

When the output characteristic data of a PV system during operation is measured such as "Field Test Program" data under New Energy and Industrial Technology Development Organization (NEDO) or private houses [1,2], this software offers quick and precise comments within a few minutes.

2. Diagnostic method

2.1. Diagnostic flow

Fig. 1 shows one example of PV systems and data from the PV system are saved into a personal computer.

However, data were sometimes not left or disordered. To diagnose the PV system by data precisely, it is necessary to ensure the quality of the acquired data and to compare them with reference data.

Reference data such as the temperature of modules, array output power, irradiation, and so on, are presumed based on the place (latitude, longitude, standard meteorological data, etc.) and installation conditions (direction, inclination and type of solar cell, etc).

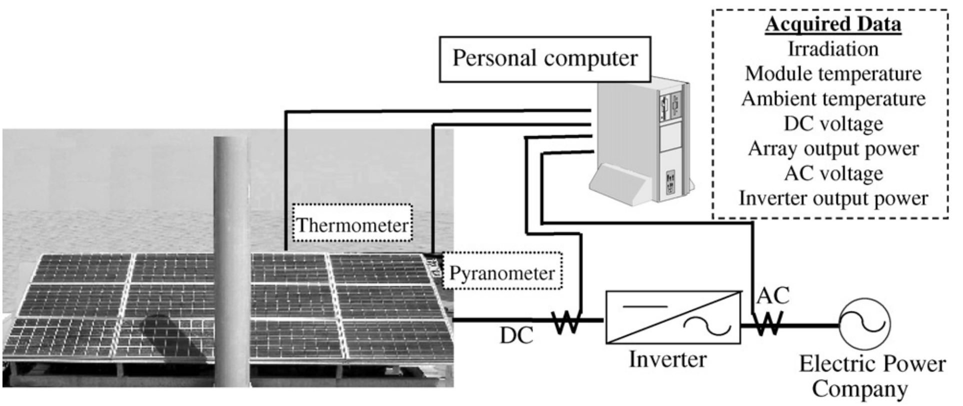

Fig. 1. PV system and data acquisition system.

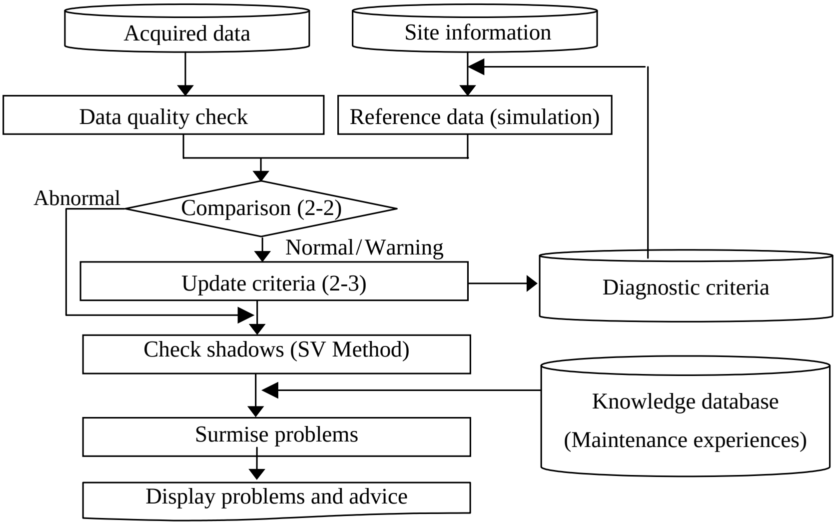

Fig. 2. Diagnostic flow.

Then, the normality/abnormality of the system is diagnosed using diagnostic criteria (2.2).

For future data diagnoses, diagnostic criteria are updated to adjust the character of the site (2.3).

To diagnose shadows on the modules and pyrometer, the SV method [3] was used.

Then problems are surmised using to the results of the diagnoses and maintenance experiences data.

Finally, this system displays like ‘‘Inverter Stopped. Please check the Inverter’’.

Fig. 2 shows the diagnostic flow.

2.2. Data diagnosis

To diagnose the normality/abnormality of the system, the ratio of the acquired data to reference data is calculated. When actual meteorological and average meteorological data (from the Meteorological Agency) are close, the ratio becomes nearly equal to ‘1’.

One example of such data diagnoses is the following: when the ratio of generated power in summer is ‘1’ and the ratio of generated power in winter is ‘0.7’, a shadow or snow on the modules in winter is presumed. In this case, ‘1’ is the criterion for the diagnosis.

2.3. Criteria and learning method

Average meteorological data such as METPV [4] are acquired at intervals all over Japan. This means that some of the PV sites do not exist near a site where meteorological data are acquired. Therefore, the weather at the site acquired for average meteorological data and that at the PV system are a little different. To account for the difference, it is necessary to adjust the criteria for diagnosis.

In this diagnosis, the ratio of acquired data to reference data indicates the difference between the site acquired for average meteorological data and the site of the PV system. For future diagnosis, criteria are updated using a ratio. As an example of updating criteria, when the criterion is '1' and the ratio of acquired data to reference data is '0.92', the new criterion is set to '0.97'. This update method influences the number of updated times, a data item, etc.

According to our actual data, inverter conversion efficiency does not fluctuate very much over the entire input range and the average was around 0.925. We decided that the criterion for inverter conversion efficiency is the constant value '0.925'. This value is adequate because almost all inverter conversion efficiency of Japanese inverter is 0.9 to 0.95.

Meanwhile the array performance ratio and system performance ratio were repeated yearly. For the two ratios, twelve month's criteria are set. Each month's criterion is updated by each month's ratio.

Table 1 shows the initial diagnostic criteria.

To diagnose the ratio of acquired data and reference data more precisely, it is classified into three diagnostic criteria ranges. These diagnostic criteria ranges are comprised of the "Abnormal data range," "warning data range" and "normal data range" (see Table 2). The normal data range has a changeable margin that was our experimental value and its center is its criterion. On the other hand, the abnormal data range is set to a constant range that was also our experimental value.

The criteria are updated monthly to adjust them to each site's characteristics when the criteria are in the "warning data range" or "normal data range". In the case of the "Abnormal data range," the criteria are not updated to prevent from misdiagnosis. It is because the abnormal data would be diagnosed as the normal data and vice versa if the criteria were updated.

Table 1
Initial data of diagnostic criteria

Data item	Initial criteria
Irradiation	1
Ambient temperature	1
Temperature on module back face	1
DC voltage	1
Array output power	1
AC voltage	1
Inverter output power	1
Array performance ratio (= Array output power/Irradiation/PV capacity)	Various (0.7–0.8)
System performance ratio (= Inverter output power/Irradiation/PV capacity)	Various (0.65–0.75)
Inverter conversion efficiency (= Inverter output power/Array output power)	0.925

Table 2
Diagnostic criteria database

Data range	Meaning of data range	Range set method
Normal data range	No problems.	The margin from its criterion.
Warning data range	The PV system may have problems.	The range between "Normal data range" and "Abnormal data range"
Abnormal data range	Major problems happened to the system data and/or the measurement equipment.	Outside of a constant threshold.

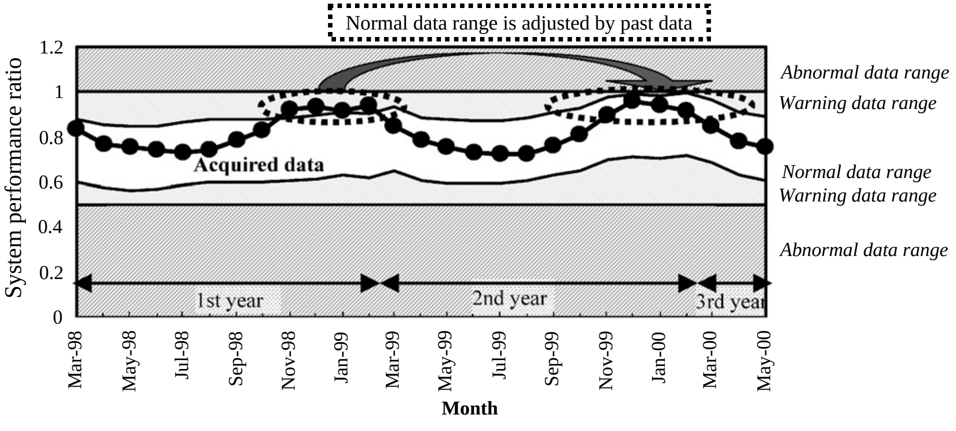

Fig. 3. Transition of system performance ratio (Normal PV system).

3. Result

3.1. Diagnosed result of a normal PV system

Fig. 3 shows the transition of the system performance ratio for an actual 3.75-kWp PV system in Hyogo Prefecture, Japan.

In the winter of the first year of use, the system performance ratio exceeded the normal data range. The reason was not due to a system problem but instead to a lower ambient temperature than the standard meteorological data. In fact, the temperature data acquired from the underside module was lower than the reference data considering the standard meteorological data by an average of 5°C. The system performance ratio in the winter should thus be judged as the "Normal data range" and this result reflected in the diagnostic criteria databases for the next year.

In the second year, the "Normal data range" in winter shifted upward based on the updated database and thus the system performance ratio is now within the "Normal data range".

Table 3 is an example of the diagnosed result of acquired data in January 2000. Based on these analyses, the expert system displays the overall comment "No problem". This proves that the updating of diagnostic criteria makes it possible to diagnose the normality or abnormality of PV systems.

3.2. Diagnosed results of a problem PV system

3.2.1. Detection of shadowing

Fig. 1 system was used to check the diagnostic method and expert system, and a telephone pole was intentionally installed in front of the 0.5-kW PV system.

In order to detect the shading effect on models, the SV method [3] was used. In addition, data was hourly analyzed for detecting the obstacles' direction. The left side of Fig. 4 shows the clear-day hourly data of reference data (considering the array temperature and irradiation) and the maximum inverter output power in March. Using the SV Method and hourly analysis, it was presumed that a shadow

Table 3
Result of a normal PV system

Acquired data	Data range
Irradiation	Normal
AC voltage	Normal
Inverter output power	Normal
Temperature on module back face	Normal
Inverter conversion efficiency	Normal
System performance ratio	Normal
Shadow on the pyranometer	No
Shadow on the modules	No

Overall comment: No problem.

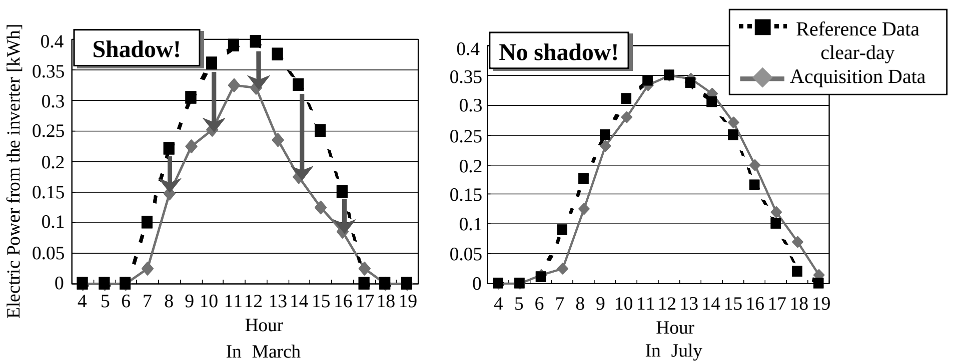

Fig. 4. Clear-day power pattern and separation of shading.

was cast on the modules from 10:00 to 15:00. On the other hand, a shadow was not cast on the modules in July (Fig. 4).

Table 4 shows the diagnosed results in March 2001. The SV Method and hourly analysis presumed that the possibility in which a shadow was cast on the modules was "very high" because of the ratio of the inverter output power to reference data and the fact a shadow was not cast on the modules in July. On the other hand, the problem of the inverter output power and system performance ratio has a "high" possibility because the inverter output power and system performance ratio were not in the "abnormal data range" but in the "warning data range".

According to these analyses, this system presumes that the shadow on the modules curbed the inverter output power and displays the overall comment "Shadow on the modules".

3.2.2. Detection of inverter stop

The inverter in the Fig. 1 system was stopped intentionally at 13:00 on December 2 and restarted at 19:00 on December to confirm whether the inverter stop would be

Table 4
Result of a problem PV system

Acquired data	Data range	Possibility
Irradiation	Normal	—
Module temperature	Normal	—
Array output power	Warning (Low)	High
AC voltage	Normal	—
Inverter output power	Warning (Low)	High
Inverter conversion efficiency	Normal	—
System performance ratio	Warning (Low)	High
Shadow on the pyranometer	No	—
Shadow on the modules	10:00–15:00	Very high

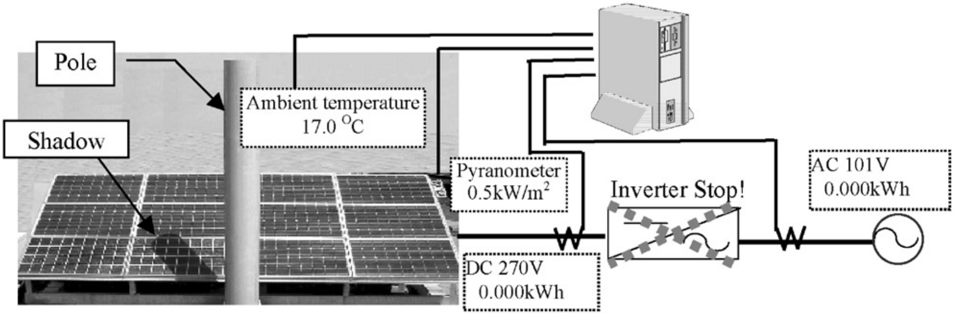

Fig. 5. Configurations and data at 14:00 on December of inverter stopped system.

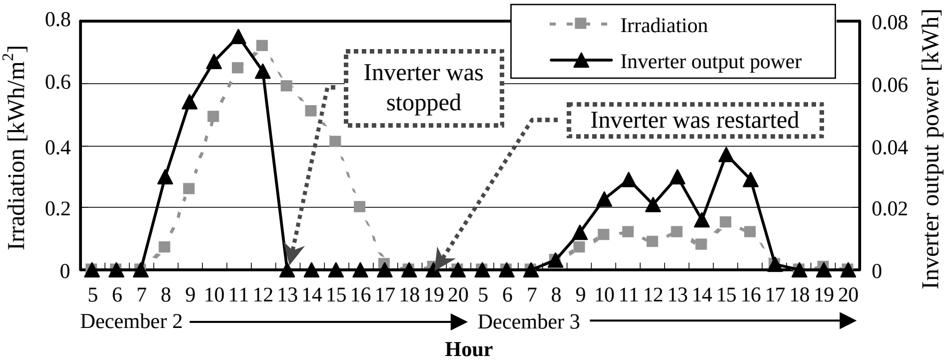

Fig. 6. Inverter output power and irradiation.

detected. Data at 14:00 on December is shown in Fig. 5. And data of the inverter output power and irradiation on December 2 and 3 are shown in Fig. 6.

In this case, diagnostic method is as follows;

(1) "AC voltage 101 V" indicates that there is no possibility that a wire between the inverter and the grid line was broken.
(2) "DC 270 V" indicates that there is no possibility that a wire between the inverter and the grid line was broken, or modules were broken.
(3) "Inverter output power 0.000 kW" indicates that there were possibilities of the inverter stopping (or malfunctioning), and/or the measurement device trouble of the inverter output power.
(4) A recovery of the inverter output data on December 3 indicates there is no possibility of the measurement device trouble of the inverter output power.

According to (1)–(4), this system displays "Inverter stopped from 13:00 on December 2 to 7:00 on December 3".

4. Conclusion

Diagnostic technology for PV systems was developed using the learning method. An expert system to provide maintenance advice from the analyzed data was also added. The accuracy of these technologies was proven in actual sites.

The special features of this diagnostic technology are as follows:

(1) Updating the diagnostic criteria makes it possible to diagnose the normality or abnormality of PV systems, taking the characteristics of the PV system and climate into account.
(2) The S V method and hourly data analysis determine where a shadow is on the modules or pyranometer.
(3) From the diagnosis result, maintenance advice is also provided.

This technology is highly useful, because it simplifies the servicing and maintenance of PV systems.

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