

An online health monitoring system for photovoltaic arrays based on the B/S architecture

Y Tian¹, Z C Chen^{1,3}, H F Zhou^{1,3}, L J Wu¹, C Long², P J Lin¹, S Y Cheng¹

¹College of Physics and Information Engineering, Fuzhou University, Fuzhou 350116, China

²Institute of Energy, School of Engineering, Cardiff University, Cardiff CF24 3AA, UK

E-mail: zhicong.chen@fzu.edu.cn/zhhafa@163.com

Abstract. In order to improve the working efficiency of the photovoltaic (PV) array inspection system, the application of online monitoring systems for the PV arrays is quickly rising. In this paper, an online PV array monitoring combining with B/S architecture, Python language, and Flask framework is developed to monitor and diagnose the status of PV arrays which can display the data of the PV array and facilitate the staff to monitor the working status of PV array. When a fault occurs, the staff can also register the fault information on the website quickly. The developed system is composed of three parts: data acquisition, data transmission and PV online monitoring website. Firstly, the system uses the Raspberry Pi3 to collect the data when the PV array operates in maximum power point (MPP), and the acquired data is stored locally in the Raspberry Pi. And then, the data is uploaded to the PC side via the FileZilla server software and further transmitted to online monitoring website. Finally, the PV array online monitoring website displays received data, and perform the fault diagnosis of PV array using a kernel based Extreme Learning Machine (KELM). Experimental results show that the total classification accuracy for ten different operating conditions can reach 97.2%.

1. Introduction

With the development of the economy, science and technology worldwide, the energy shortage is becoming increasingly serious, and renewable energy has been deployed gradually by many related individuals and institutes. As a clean energy that can be continuously used and inexhaustible, solar energy attracts more and more people's attention. Many countries in the world have built or are building a large number of PV power stations [1]. It is difficult for large-scale PV power plants to run smoothly and independently, meanwhile, the related PV equipment are needed to work together in "no fail" operating state to maintain the normal operating of PV plants. It can be easily found that PV plants are mostly built in remote and harsh outdoor environments. Monitoring and maintenance of widely dispersed PV systems require a lot of manpower and material resources. Therefore, in order to prolong the operating life of PV plants and avoid accidents caused by equipment damage such as fire,



it is particularly important to establish a reliable online monitoring system for PV arrays to ensure the safe and stable operation of PV system.

At present, most PV plant monitoring systems use the Client/Server architecture, which requires an installation of client software, high maintenance costs, short communication distances, low data transmission rates, low reliability, and lack of openness. In the past decade, various data acquisition systems with low efficiency were developed. These data acquisition systems transmit data through physical connections, ordinary desktop computer is used for data processing and generate graphs [2]. At present, the application of commercial monitoring systems for PV plants still has some disadvantages, such as using software from the same manufacturer, limited autonomous control, huge power consumption, limited storage capacity, and high maintenance costs [3]. For remote network monitoring technology, some solutions were presented by many domestic and foreign scholars. N C Batista et al used open source tools and ZigBee technology to develop a system without fault diagnosis for PV and wind energy monitoring [4]. Corresponding fault diagnosis, Farid Touati et al proposed an online monitoring solution based on ThingSpeak, which is an open platform for the Internet of Things [5]. However, this system behaves poor in scalability. The Raspberry Pi and Internet of Things (IoT) are applied to design a multi-user remote system by Hu Y et al [6]. A scheme for accessing the Internet through a web server built on the Raspberry Pi is proposed by Ozbay H et al [7]. In above monitoring systems, the operating parameters of PV system are monitored, the collected PV data is analyzed and processed, and the collected data is aggregated into a database to complete the report production for the real-time working status monitoring and data management. It can be seen that the PV plant monitoring system is becoming more and more mature, but it lacks the record of the failure information of the PV array and the safety of the website users. Additionally, most of the current embedded data gateway is PC-based and embedded-based solutions. Gateways based on PC solutions are not only lack of flexibility but also more expensive. The gateway which adopts single-chip microcomputer as the core controller has difficulties in system upgrade, maintenance and debugging due to the limited resources of the single-chip microcomputer. These on-line PV monitoring and fault diagnosis systems have several drawbacks as follows: relatively poor flexibility and scalability and acquire a lot of manpower and material resources.

To ensure the safe and stable operation of PV arrays and avoid equipment damage and accidents, it is necessary to establish a convenient data acquisition system and a reliable online monitoring website for PV arrays. The Raspberry Pi 3 development board has the advantages of small size and powerful functions. Therefore, it is appropriate to use it for data acquisition, storage and transmission. Python has the advantages of high efficiency, simplicity and strong scalability. It has been widely used in WEB website development in many fields such as bioengineering [8-10]. Additionally, the artificial intelligence provides new ideas for PV fault diagnosis methods [11]. Flask is a lightweight web application framework written in Python that is ideal for web development. Therefore, the Flask framework, CSS, JavaScript, and SQLite3 database are utilized for the development of the PV array online monitoring website in the paper. In addition, the Extreme Learning Machine (ELM) of the kernel function is applied for fault diagnosis algorithm in presented website. The learning speed of ELM is fast and the accuracy is high, which turns out that the proposed fault diagnosis algorithm is very suitable for the detection of PV faults [12, 13]. The KELM fault diagnosis algorithm can also combine a reconstruction algorithm proposed in [14], which can increase the system's stability and flexibility to improve the life of PV array.

The rest of paper is organized as follows. Section 2 describes the system architecture, which outlines the overall system functionality. Section 3 introduces how to collect data. Section 4 describes how to upload data to the PV array health monitoring website. Section 5 illustrates the function of the PV array health monitoring website. Section 6 introduces a KELM fault diagnosis.

2. System architecture

The designed system consists of three parts: data acquisition, data upload, and PV monitoring website. The data acquisition is connected to the sensing circuit through the GPIO port of the Raspberry Pi 3, which is used to receive the PV array voltage and each string current under MPP condition. The data upload is mainly used to bridge the sensor monitoring network and the remote online monitoring server of the PV array. It collects and sends the PV-array data to the remote online monitoring server. The architecture of the monitoring system is shown in figure 1 and the whole system of PV monitoring is shown in figure 2.

The server adopts the B/S architecture. Stable and reliable network communication can be established with each PV array through the Raspberry Pi to collect the parameters of different PV arrays. At the same time, a local database is set up to save the operating parameters of each PV array. In addition, the fault diagnosis algorithm is integrated on the server to identify the working status of the PV array. When a fault occurs, the relevant personnel can record the fault information on the server and notify the on-site personnel to eliminate the fault quickly.

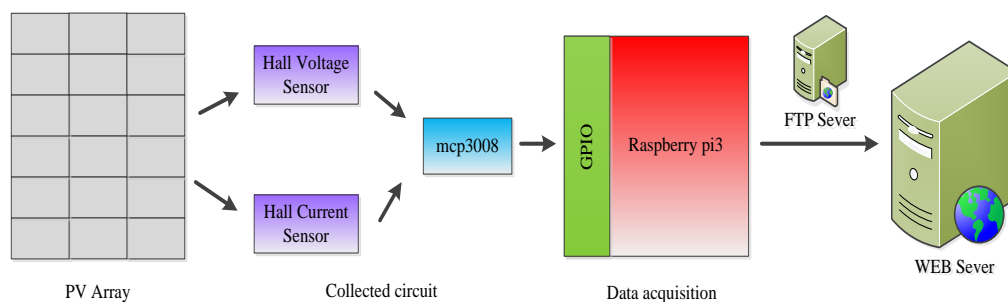


Figure 1. The architecture of the monitoring system.

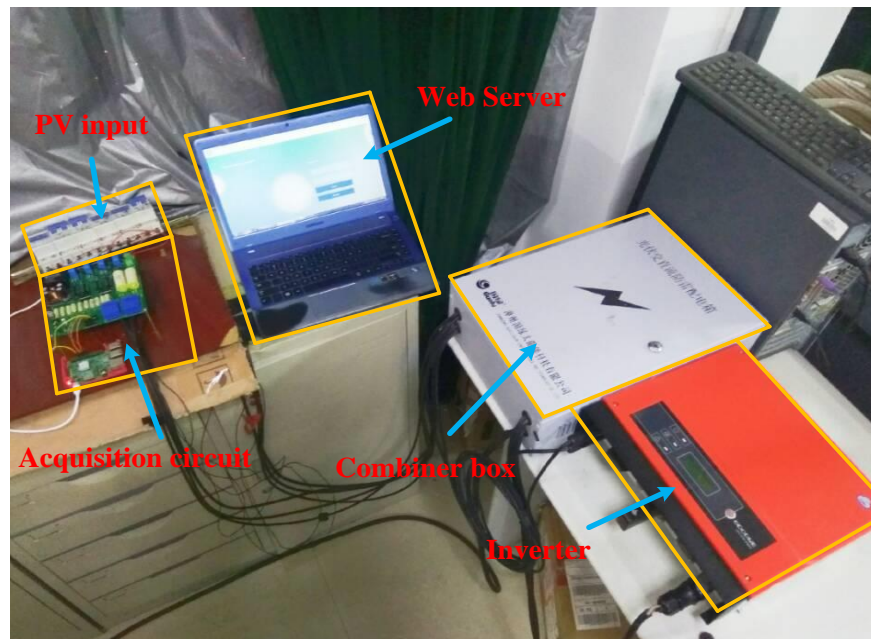


Figure 2. The whole PV monitoring system.

3. Data acquisition and upload

The system uses the Raspberry Pi to collect PV data. The Raspberry Pi is a very cheap, palm-sized fully programmable computer. The Raspberry Pi for data collection is more appropriate due to its compactness and convenience. However, the Raspberry Pi does not have an internal analog-to-digital converter. Therefore, an external analog-to-digital converter is required for data acquisition.

The system's acquisition circuit is shown in figure 3. It is made up the following small modules: power supply module, voltage acquisition module, current acquisition module, digital-to-analog conversion module. Power supply module is used to provide the power for entire circuit. This circuit needs to use +12V, +5V, +3.3V, -12V voltage. Therefore, a voltage conversion circuit is required to convert the 220V commercial power to the above voltage values. The voltage acquisition module uses the voltage Hall sensor to convert the PV-array voltage into a lower value, and then output to a digital-to-analog conversion circuit for digital-to-analog conversion. The current acquisition module is similar to the voltage acquisition module. The difference is the current value collected by the Hall current sensor is converted into a voltage value by a formula. Digital-to-analog module is implemented by the MCP3008 chip, which converts the voltage values received from the eight channels to digital. The MCP3008 is a low cost 8-channel 10-bit analog-to-digital converter which connects to a Raspberry Pi via a software SPI connection. Thus, the Adafruit MCP3008 Python library can be installed for better acquisition. The data acquisition flow chart is shown in figure 4.

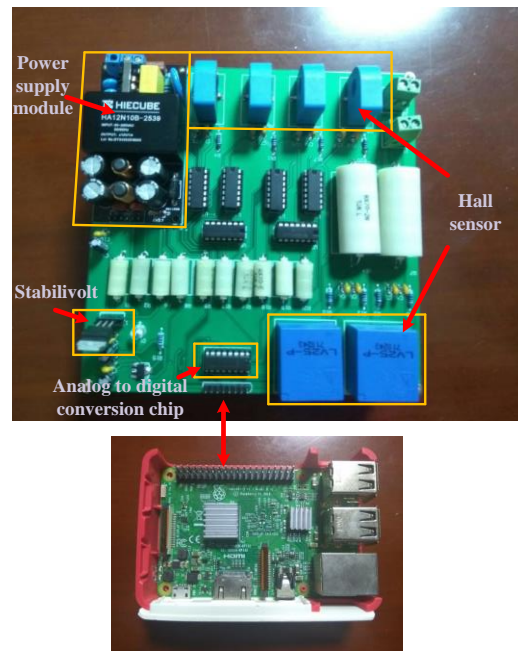


Figure 3. The system's acquisition circuit.

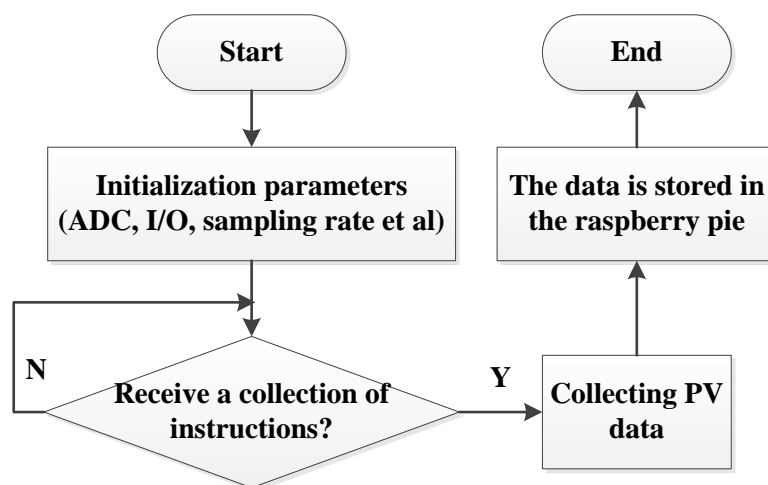


Figure 4. The data acquisition flow chart.

The data upload takes the Raspberry Pi3 as the core board, which caches the collected parameters (including current, voltage, etc.) to the local database so that related personnel have access to inquire. And then the data is uploaded to the cloud monitoring center site with FileZilla tool for unified management.

FileZilla is a convenient and efficient FTP (File Transfer Protocol) client tool with some advantages such as controllable, organized interface and simplifies the management of multiple sites. FileZilla Server is a flexible and convenient FTP server software that supports FTP and SFTP (Secure

File Transfer Protocol). In order to convenient the server's call, user can click "Connect" button to connect the Raspberry Pi to the server through inputting the hostname or IP address, username, password of the Raspberry Pi.

4. PV array health monitoring website

The PV array online monitoring server serves as a remote data processing center for unified management and scheduling. The design of server includes the client layer, application layer, and data layer. The Python syntax is concise and clear, with a rich and powerful class library. Flask supports all relational databases, especially with the SQLite database. It has high efficiency, good system security, stability, and scalability. Therefore, the realizing method is based on SQLite database platform, using Flask framework and Python technology. The development environment of the system adopts the configuration scheme of Windows + Apache + SQLite + Python, combined with the development of a powerful and elegant Flask framework.

The client layer is mainly the user's browser which adopted B/S architecture. Its distributed feature allows the user to access the server through the browser whenever and wherever the network is available. In addition, the B/S architecture is simple to develop and has strong sharing. What's more, the business expansion and maintenance are simpler and more convenient. Only by adding or changing web pages, the server function can be increased and the user information can be synchronized and updated.

The application layer includes a control layer, a business logic layer, and a basic service layer. On the control layer, the RESTful API is designed to receive the data submitted by the client through the HTTP post. And it performs the corresponding session management and parameter analysis. The REST concept separates the API structure and logic resources, which operates the resources through the Http methods (such as GET, DELETE, POST, and PUT). On the business logic level, it is mainly composed of user management, data visualization and message management. Especially, the PV operating data visualization function is completed through the ECharts module.

The data layer is divided into a data access layer and a data storage layer. The data database adopts the SQLite. SQLite is a lightweight SQL database implementation. Different from MySQL, SQLite does not run as a stand-alone server. It only provides an interface library for accessing database files on disk, which has the advantages of ease use and low cost. SQLite is an associated database. And it stores data in different tables instead of storing all the data in a large repository, which increases the speed and flexibility.

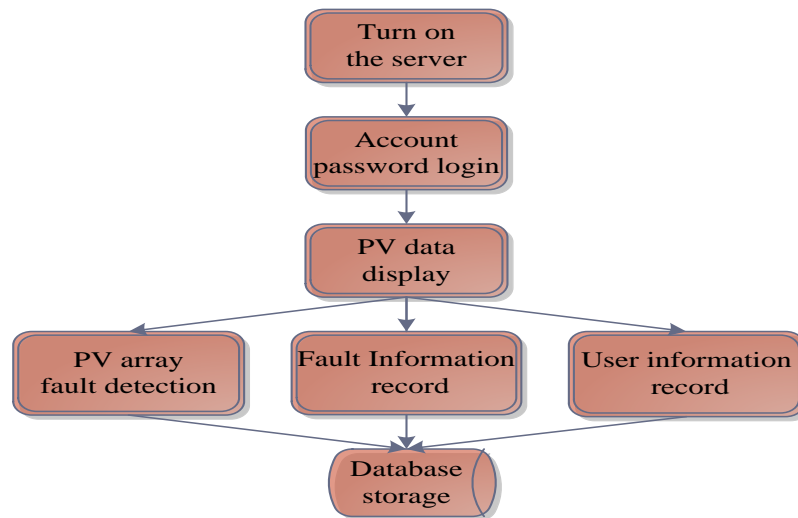


Figure 5. The specific server process.

This paper has designed and built an on-line monitoring system to provide real-time monitoring of PV power plants in different regions. On the server, the collected working status parameters of PV array can be displayed, and real-time diagnosis of typical PV faults can be performed. The cloud monitoring center website can record the occurrence of fault information and save it locally to facilitate the viewing of the workers. Relevant personnel can browse the output parameters of PV array regularly through the browser. When the fault occurs, the fault type of the PV array can be understood from these parameters and then the staff is notified so that the solution can be quickly made. The specific server process is shown in figure 5. The website of this system mainly consists of user login, data display, fault information recording and fault information viewing. The voltage display on the web page as an example is shown in figure 6.



Figure 6. The voltage display on the web page.

5. Kernel based extreme learning machine fault diagnosis of PV array

The single hidden layer feed-forward neural network has a good learning ability. Therefore, it is widely used for fault diagnosis of PV array. However, some disadvantages of traditional learning algorithms limit its development. Feed-forward neural network mostly uses the gradient descent method. This method has some disadvantages such as slow in training, easily falls into local minimum points, cannot reach the global minimum, and the selection of learning rate is sensitive. To solve these problems, the ELM algorithm randomly generates the connection weight ω and the threshold b for hidden layer, and they don't need to be adjusted during the training. Only the hidden layer nerves need to be set in order to obtain the unique optimal solution, which makes ELM have the advantages of fast learning and good generalization performance.

The block diagram of ELM fault diagnosis network model of PV array is shown in figure 7. In addition to the normal working condition, this paper simulates nine common faults: short circuit 1, short circuit 2, line-line fault with one module shorted (LL1), line-line fault with two modules shorted (LL2), degradation of the array, degradation of the string, shadow 1, shadow 2, and open circuit. Short-circuit 1 and short-circuit 2 refer one module and two modules in a string of PV module are short-circuit respectively. LL1 and LL2 refer one module and two modules between different strings are short-circuit respectively. Shadow 1 and shadow 2 refer one module and two modules are blocked respectively. The corresponding working status of PV array is given different labels from 0 to 9. The PV array used in this system is three parallel strings, and each string consists of six PV modules in series. Since the PV array generates corresponding voltage and current under MPP condition, the four features vector including the PV-array voltage V and the three currents of strings I_1 , I_2 , I_3 are selected as data samples. After filtering and extracting processing, they would be as input vectors. Since ELM can randomly generate ω and b before training, only the number of hidden layers neurons and infinitely different hidden layer neuron activation function are set to calculate the connection weight β between the hidden layer and the output layer. The number of neurons in the hidden layer will affect the performance of the ELM, but it does not mean that the more neuron has the better performance. Too many hidden layer neurons will not only reduce the accuracy of classification but also increase the burden of calculations. The accuracy of each fault is shown in table 1 and algorithm flow chart of proposed KELM is shown in figure 8.

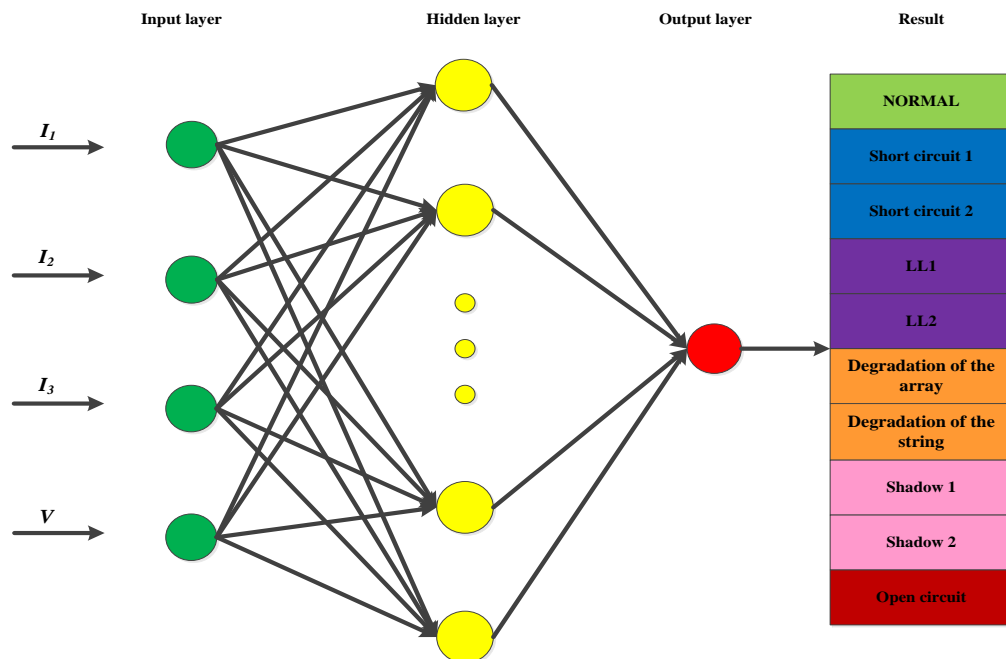


Figure 7. The block diagram of KELM based fault diagnosis model for PV arrays.

Table 1. The accuracy of fault diagnosis.

Type	Accuracy (%)	Type	Accuracy (%)
Normal	96.37	Short circuit 1	93.21
Short circuit 2	94.19	LL1	99.50
LL2	94.64	Degradation of the array	94.82
Degradation of the string	100.00	Shadow 1	91.67
Shadow 2	99.04	Open circuit	100.00

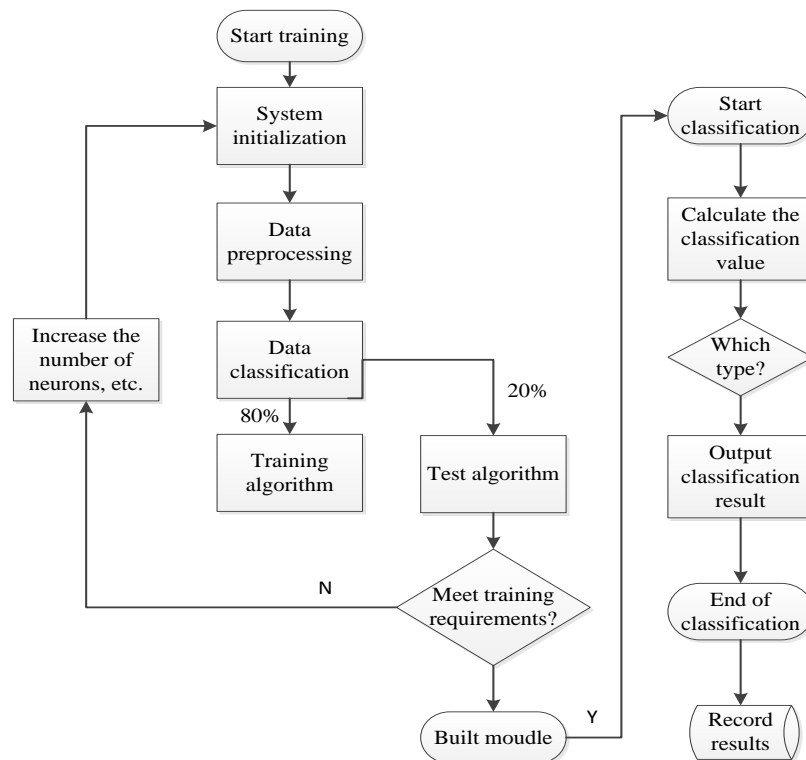


Figure 8. Flow chart of the proposed KELM algorithm.

6. Conclusion

This paper mainly develops an online monitoring system to monitor the working status of PV array, which consists of a data acquisition board, a Raspberry Pi based data gateway and a web server. Firstly, the data acquisition board is composed of a power supply module, a voltage acquisition module, a current acquisition module, and a MCP3008 based digital-to-analog conversion module. Raspberry Pi3 is connected to the designed sensing board through the GPIO port. Secondly, Raspberry Pi3 receives the data of PV arrays and stores them locally, and then the data is sent to the server for the server calling through Filezilla client tool. Finally, the server receives the data and displays it on the webpage. It is convenient for the staff to remotely monitor the working status of PV arrays. In addition, the server provides a platform to achieve online fault diagnosis, and an efficient KELM fault diagnosis is used to identify the faults in this study. At the same time, the staff can record the fault information on the webpage. The developed system can complete the functions of real-time monitoring and fault diagnosis of PV arrays, which has a certain practical value for the appication of PV health monitoring.

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