Dynamic Monitoring and Optimization of Fault Diagnosis of Photo Voltaic Solar Power System Using ANN and Memetic Algorithm

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Abstract

Most of the photo voltaic (PV) arrays often work in harsh outdoor environment, and undergo various faults, such as local material aging, shading, open circuit, short circuit and so on. The generation of these faults will reduce the power generation efficiency, and when a fault occurs in a PV model, the PV model and the systems connected to it are also damaged. In this paper, an on-line distributed monitoring system based on XBee wireless sensors network is designed to monitor the output current, voltage and irradiation of each PV module, and the temperature and the irradiation of the environment. A simulation PV module model is established, based on which some common faults are simulated and fault training samples are obtained. Finally, a memetic algorithm optimized Back Propagation ANN fault diagnosis model is built and trained by the fault samples data. Experiment result shows that the system can detect the common faults of PV array with high accuracy.

Keywords

Photo Voltaic (PV), Artificial Neural Network (ANN)

1. Introduction

Due to the increasing depletion of fossil energy resources and the increasing environmental pollution, many countries in the world are actively seeking alternative renewable clean energy [1]. Solar PV power generation has the advantages of clean, no pollution, sustainability and broad [2]. Therefore, the use of solar power has been widely valued by many countries [3]. However, the PV array works in the complex outdoor environment. The local material aging, open circuit or short circuit and other problems

are easy to appear. These problems greatly reduce the battery life. At the same time, the failure of the PV array will reduce the power generation efficiency, and even the fire will happen when they are serious enough, endangering the safety of social property. The fault detection of PV power generation is very essential.

The routine preservation of PV power generation system mainly relies on artificial periodic cleaning solar panel, PV module connection and between the component and the support, and the inverter voltage and current monitoring data manual judgment whether the normal power generates [4]. This method is time-consuming, lack of real time, dependent on the subjective experience of maintenance personnel which is difficult to find and identify faults quickly and accurately. In order to overcome the difficulty and subjectivity of artificial detection of PV power generation system, the monitoring technology of PV power generation system is concerned by many domestic and foreign scholars and related organizations. Offline monitoring system mainly includes the infrared image analysis method, the ground capacitance measurement method, based on the parameter model of the fault diagnosis method. Online monitoring system mainly includes the satellite detection method, the fault diagnosis method based on the working voltage window, the time domain analysis method and so on. Drews uses the satellite to observe the light intensity data in the area of the PV array, and inputs it to the model of the photo voltaic array to get the power output of the simulation. We determine whether exits fault by comparing simulation powers obtained with actually powers detected [5]. A fault detection method based on power loss analysis is proposed by Chouder [6]. The parameters of the electrical model of the array are fitted by using the measured I-V curve of the PV array. The expected output power is obtained by combining with the measured ambient light intensity and component temperature. Comparing the expected power with the measured power, it is used to determine whether the array is in fault. Gokmen [7] proposed a fault diagnosis method based on the working voltage window. The number of open circuit and short circuit faults can be detected by the range of the series voltage. Considering the cost and the complexity of the system, the monitoring system is mostly realized by the array level/component level monitoring. These systems can not accurately obtain the location of faulty PV modules.

PV module fault has the characteristics of fuzzy and multilevel. In order to distinguish the fault types, the intelligent algorithm is introduced to the fault diagnosis. The neural network method proposed by Syafaruddin. By establishing and training several neural network structure [8], he judges whether there is a short circuit fault. An online diagnostic method based on BP neural network is proposed by Spataru, S and Sera, D [9]. In order to distinguish three states of the components, including normal, short and abnormal aging, it use the open circuit voltage of photovoltaic module, short-circuit current, maximum power point voltage current as the inputs of the trained neural network. In these methods, the number of feature variables used in fault diagnosis is limited, and the characteristic variables are difficult to measure in practice. Therefore these methods can only distinguish the limited fault causes and manipulate the accuracy of fault diagnosis.

In order to obtain the location of PV module, the real-time fault monitoring based on component level is a necessity. At the same time, in order to improve the accuracy of fault diagnosis, the correct use of intelligent algorithm is also an unavoidable. With the continuous progress of low-cost wireless sensor technology, you can install a wireless sensor on each PV module. In this subject, we use algorithm based on distributed on-line monitoring of photo voltaic array of XBee wireless sensor network and Artificial neural network algorithm based on memetic algorithm optimization to study fault diagnosis. Because the PV system have the unpredictable nature of the various faults, fault types and the fault performance characteristics are not easy to be diagnosed by environmental factors. In this paper, an online fault diagnosis method based on Artificial neural network is proposed. The model can store the corresponding relationship between the failure state of PV modules and the causes of faults in the structure of the neural network. So the data that input to the trained neural network can judge whether the components are faulty or the type of fault, so as to realize the on-line fault diagnosis of PV modules [5] [10] [11]. The way ensures the output efficiency and normal operation of PV power plant, saving a lot of material resources and manpower.

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2. Online Monitoring System

The on-line monitoring system that is designed by this paper is mainly composed of the PV module wireless acquisition module, data gateway and remote data management center. The XBee network nodes that are embedded in the PV cell module are the monitoring unit of the whole system. Their work is a real time acquisition of the output parameters of PV modules, and the acquisition data is transmitted to the data gateway by the serial port. The data gateway is the buffer, and the data is transmitted to the remote data management center. When the data management center receives this collection of data, it is to carry on a series of processing and storage. So it can get the fault type and location of PV modules.

All the monitoring nodes in the system adopt the same design principle. They are directly mounted on the PV panels. The monitoring node is composed of power supply module, sensors, collection module and wireless transceiver module.

Communication Modes

The XBee supports both an AT (Attention) and an API (Application Programming Interface) mode for sending and receiving data at your controller. Both have their advantages.

In AT Mode, also called Transparent Mode, just the message data itself is sent to the module and received by the controller. The protocol link between the two is transparent to the end user and it appears to be a nearly direct serial link between the nodes. This mode allows simple transmission and reception of serial data. AT Commands are used to configure the XBee, such as to send the data to a node with an address. AT Commands and examples will be explored in more depth later, but the process requires placing the XBee into Command Mode, sending AT codes for configuration, and exiting the Command Mode. Note that even though the transmission and reception is the raw data, the message itself is passed between nodes encapsulated with needed information such as addressing and error checking bytes.

In API Mode, the programmer packages the data with needed information, such as destination address, type of packet, and checksum value. Also, the receiving node accepts the data with information such as source address, type of packet, signal strength, and checksum value. The advantages are the user can build a packet that includes important data, such as destination address, and that the receiving node can pull from the packet information such as source address of the data. While more programming intensive, API Mode allows the user greater flexibility and increased reliability in some cases. Both sides do not need to be in the same mode. Data may be sent in API Mode and received in AT Mode or vice-versa. The mode defines the communications link between the PC or controller and the XBee modem, and not between XBee modules. Data between XBee modules is always sent using the IEEE 802.15.4 LR-WPAN protocol. Examples using AT and API Modes will be explored.

Wireless communication module is the important data transmission channel in the system. The data transmission and networking function between the nodes and the sink node, the node and the node are realized. In this design, each component string is composed of a cluster, and the sensing node of a certain component is used as the cluster head. A star topology is used to cluster the first and the cluster members, and cluster head and sink node are also used in the topology of the network. Each cluster head sends data to the sink node. The sink node forwards the data to the data gateway by the serial port.

3. Fault Diagnosis

Because PV power generation system works in a relatively harsh environment, such as deserts, mountains or roofs. So it is easy to have a more common failure. In this paper, four kinds of fault are studied, such as short circuit, open circuit, shadow and abnormal aging. The output of PV modules is influenced by environmental factors. The output characteristic of the components and the environmental factor is the nonlinear relationship. Therefore, the problem of fault diagnosis of PV modules is a complicated

nonlinear problem. Artificial neural network algorithm is introduced to realize the on-line fault diagnosis of components. The algorithm is currently widely used and mature.

The fault diagnosis model is shown in Figure 1. The model has 3 layers, which are input layer, hidden layer and output layer respectively.

The feature selection based on ANN neural network is very important for the feature selection of PV fault diagnosis model, which can improve the accuracy of fault diagnosis. Considering the actual measurement problems and related theory research, we will be the input variables of the neural network with the maximum power point voltage, the maximum power point current, the ambient light intensity, and the ambient temperature. As the PV module has an open circuit fault, the staff can directly obtain from the measured data. Therefore, in this paper, it is not the fault type of Artificial neural network. Normal, short circuit, abnormal aging, the shadow will be as neural network output variable.

Learning Algorithm

BP neural network training process will have a great impact on the accuracy of the fault diagnosis of PV modules [12]. The traditional BP neural network has a lot of problems, such as slow convergence speed, falling into local minimum easily, and low accuracy. At present, many scholars have put forward the related improvement algorithm. Such as Levenberg-Marquardt (LM) algorithm, additional momentum method, etc. By comparison, this paper finally decided to use the memetic algorithm to optimize the neural network. The algorithm can improve the convergence speed and the accuracy of network training [13].

Memetic algorithm optimization of Artificial neural network is mainly divided into three parts namely Artificial neural network structure determination, memetic algorithm
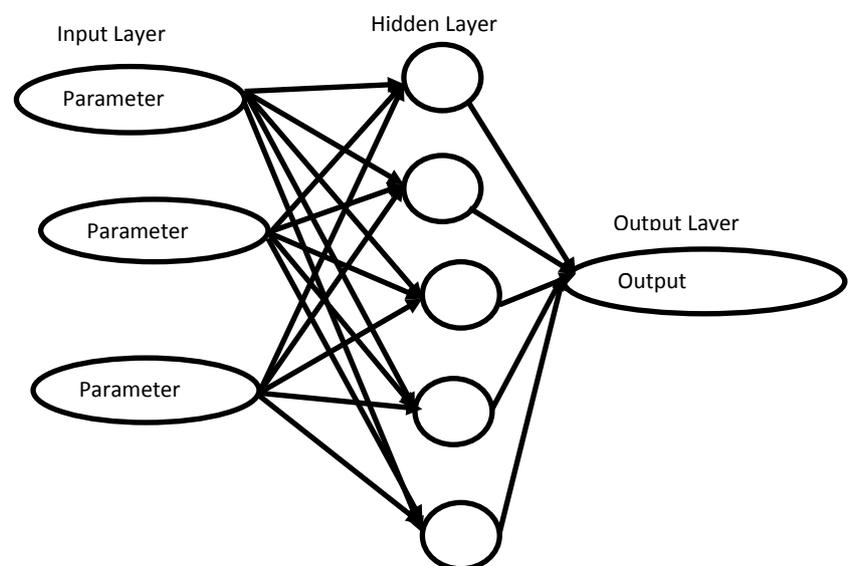

Figure 1. Artificial neural network model.

optimization weight and threshold, Artificial neural network training and prediction. The memetic algorithm parameters are the initial weights and thresholds of Artificial neural network. Provided that the network structure is known, the number of weights and thresholds can be known. The weights and the threshold of the neural network are randomly initialized to [−1, 1]. This initialization parameter will have a great impact on the network training, but it is often impossible to obtain accurately [8]. Memetic algorithm is introduced to optimize the initial weights and thresholds. The process of the algorithm is shown in Figure 2:

Memetic algorithm optimizing Artificial neural network is used to optimize the initial weights and thresholds of the Artificial neural network. Each individual in the
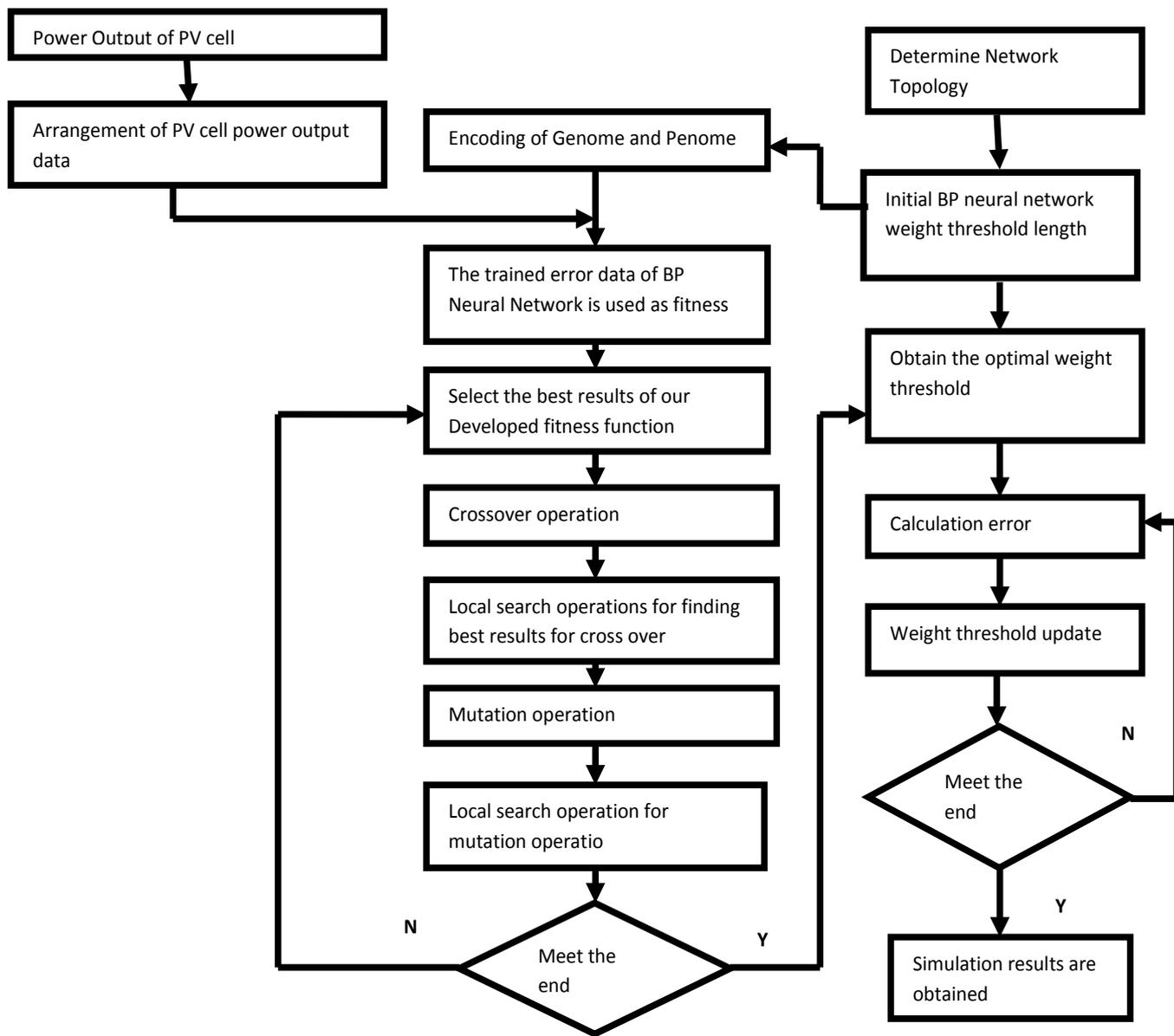

Figure 2. Flow chart for memetic algorithm optimization of artificial neural network model.

population contains all the weights and thresholds of a network. The fitness function is applied to calculate individual fitness value. The memetic algorithm finds the optimal fitness value corresponding to the individual by choosing, crossing and mutation operation. Artificial neural network prediction uses memetic algorithm to get the optimal individual to the network initial weights and threshold assignment, and the network is trained to predict the function output. In this paper, the Artificial neural network structure is set up to 4-11-4. The input layer consists of 4 nodes and the hidden layer consists of 11 nodes and the output layer has 4 nodes. There are 4 * 5 + 5 * 4 = 40 weight and 11 + 4 = 15 threshold in total. So the memetic algorithm individual encoding length is 40 + 15 = 21. At the same time, The absolute value of the prediction error of training data is the individual fitness value, and the smaller the fitness value of the individual is, the more excellent the individual is.

4. Simulation Analysis

The PV array model is built in Mat-lab/Simulation. So as to collect data from different types of fault, it is necessary to classify the PV array model. For abnormal aging fault, we choose the series of external resistance to simulate and the size of resistance represents the aging degree. In the sampling data, the selection of resistance is 1, 3, 7, 10 Ω resistor and the simulation data of different aging degrees are gotten. For the shadow failure, this paper uses the light intensity of different gains to obtain different degrees of light intensity. For the short circuit fault, this paper uses the small resistance of 5 Ω in parallel to the output of the PV modules; thus it can simulate the short-circuit fault of PV modules.

In the light intensity (100 - 1000, step size to 50) and module temperature (25 - 36, step size to 1), the maximum power point voltage and the maximum power point current are sampled respectively, and the standard simulation data for each fault type are completed. According to the above four different models of the PV model, we can extract four types of corresponding feature data. The extracted data are stored in data 1, data 2, data 3, and data 4 database files. Each group of data is 5-dimensional. The first dimension is the number of fault types, and the other 4-dimension is the fault type of data. Then the four types of data are combined into a group. In these data, the 1600 groups of data are randomly selected as training data, and the 400 groups of data are used as test data. The training data were normalized. The expected output value of each group's fault categories on the basis of the category identification is set. For example, when the identity of the class is 1, the expected output vector is [1 0 0 0], which means that the desired output is normal type.

MATLAB Simulation Results

By using memetic algorithm to optimize the Artificial neural network, we can find out the initial weights and thresholds of the network, and the optimal initial weights and thresholds are assigned to the neural network. Predicting the forecast data in the trained Artificial neural network, the results obtained are as shown in Figure 3.
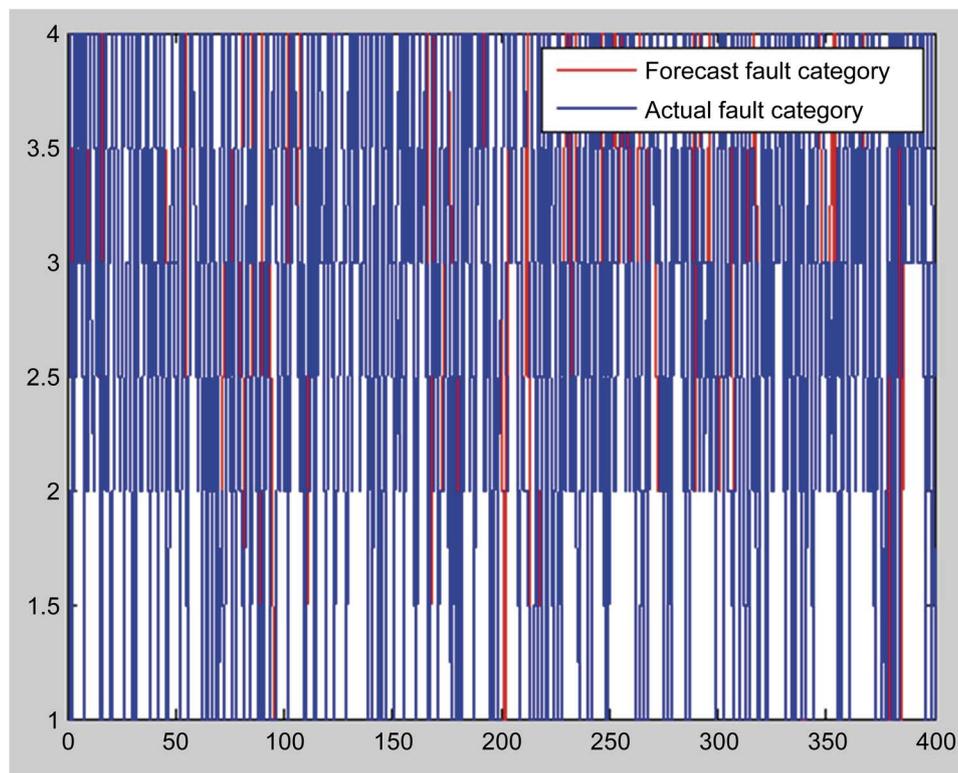
Figure 3. Comparison between prediction and actual failure value.

Memetic algorithm optimizing Artificial neural network is used to optimize the initial weights and thresholds of the Artificial neural network. Each individual in the population contains all the weights and thresholds of a network. The fitness function is applied to calculate individual fitness value. The memetic algorithm finds the optimal fitness value corresponding to the individual by choosing, crossing and mutation operation. Artificial neural network prediction uses memetic algorithm to get the optimal individual to the network initial weights and threshold assignment, and the network is trained to predict the function output. In this paper, the Artificial neural network structure is set up to 4-11-4. The input layer consists of 4 nodes and the hidden layer consists of 11 nodes and the output layer has 4 nodes. There are 4 * 5 + 5 * 4 = 40 weight and 11 + 4 = 15 threshold in total. So the memetic algorithm individual encoding length is 40 + 15 = 21. At the same time, The absolute value of the prediction error of training data is the individual fitness value, and the smaller the fitness value of the individual is, the more excellent the individual is.

In this paper, the electrical parameters and environmental parameters of PV modules are acquired by XBee sensor node, and the data is transmitted to the gateway through the XBee wireless sensor network. The faults are detected by a trained Artificial neural network. A memetic algorithm is used to optimize the Artifitial neural network fault diagnosis model. The model can detect four types of PV array operating condition, including normal, short circuit, shadow, abnormal aging. Since the open circuit fault can be directly detected from the acquired data, it is not treated as the output fault type of
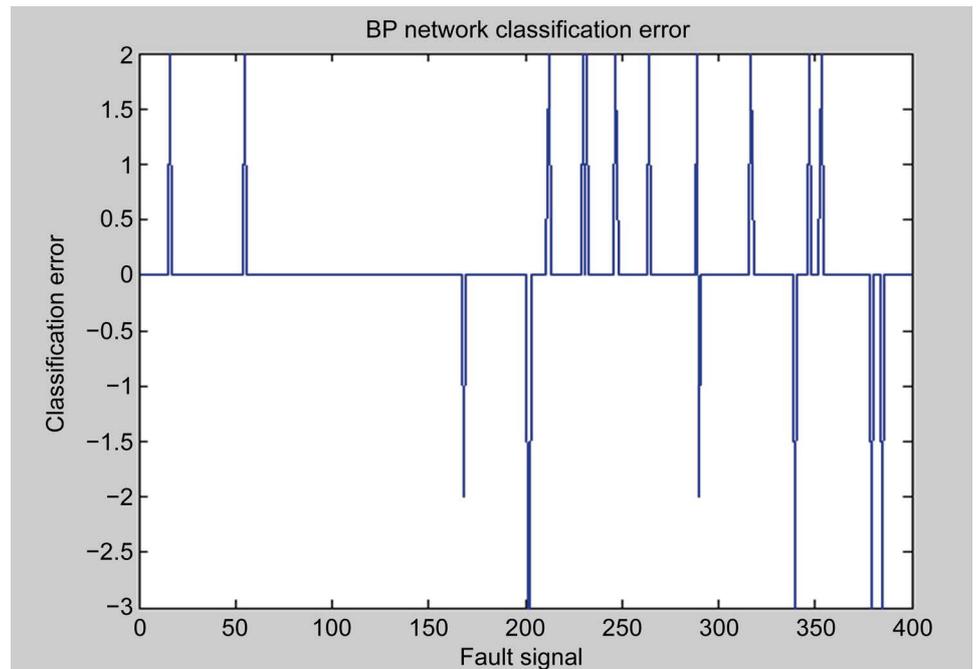
Figure 4. Artificial neural network classification error.

Table 1. Diagnostic accuracy.

Fault signal category	Normal	Short circuit	Shadow	Aging
Correct recognition rate	1	0.6982	1	0.9795

the diagnosis model. Simulation results show that the fault diagnosis system features high accuracy. Through the designed system, the operators or managers can log in to view the parameters of each PV module, and quickly find out the location of the fault PV module.

From Figure 4 we can also identified that the Neural network based on memetic algorithm has high precision and it can accurately classify the type of fault. In the random sample of 500 sets of test data, the number of the fault of every set is compared with the total number of the corresponding categories, which can be obtained each class of diagnostic error rate. Thus the accuracy of the algorithm is obtained. Specific simulation results are shown in Table 1. The short circuit fault model is lower than the other three types. I have tried many methods to simulate by changing the implicit node, learning rate, population size and the number of iterations. The results are almost the same as above. The simulation results are obtained by varying the value of the implicit nodes, learning rate, population size and the number of iterations. At this point, The implicit node is 0.1 and the learning rate is 11, and the population size is 15 and the iteration number is 10.

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