Research on Islanding Detection Based on Wavelet Transform and BP Neural Network

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Abstract: With the development of distributed generation (DG), island detection is an important technology for distributed generation. This paper proposes the use of wavelet transform and BP neural network, combined with passive detection method for island detection. By extracting the voltage at the point of common coupling (PCC) and the current value output by the inverter, wavelet transform is used as the input of the BP neural network, and the occurrence of the island is determined by pattern recognition. The method can effectively improve the island detection speed and reduce the Non-detection zone (NDZ). In addition, since the method does not require the addition of a disturbance signal, it does not affect the power quality.

1. Introduction

With the rapid development of distributed generation, the scale is getting bigger and bigger, and island detection is a problem that cannot be ignored. An island is an off-grid state in which the distributed generation powers the load separately due to a failure of the grid. When an island state occurs, the voltage and frequency of the distributed generation system will fluctuate, destroying the stability of the system, causing damage to the power equipment and causing personal injury to the maintenance personnel[1-2]. Therefore, when an island state occurs, timely detection and corresponding protective measures should be taken to reduce damage to the distributed power generation system.

At present, there are three types of island detection methods: remote, passive and active island detection. The passive islanding method is to collect the electrical quantity and determine whether it exceeds the threshold range to detect the island state. The principle is simple and easy to implement, but the Non-detection zone is too large. Active island detection includes active current disturbance method, positive feedback frequency migration method, low frequency phase disturbance method, sliding mode frequency migration method, etc. The active detection method has a small dead zone, but has a great influence on the power quality of the power grid[3-4].

Aiming at the shortcomings of passive and active island detection methods, this paper proposes island detection by wavelet transform and BP neural network. The method collects the voltage value at the PCC and the inverter output current value for wavelet transform, extracts the eigen values of the two sets of parameters, and uses it as the input of the BP neural network pattern recognition to judge the occurrence of the island. This method does not affect the power quality of the grid because no disturbance current is added. And the effectiveness of the simulation model verification algorithm is built in MATLAB/Simulink.

2. Overview of Wavelet Transform and Principle of BP Neural Network

2.1 Island Detection Principle

In this paper, for the distributed grid grid-connected operation system, when the grid fault causes

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the pull switch to open, the distributed generation continues to supply power to the local load, and the island state should be detected in time. Therefore, an island detection method based on wavelet transform and BP neural network is proposed. By extracting the voltage value at the PCC and the output current value of the inverter, the wavelet coefficients are extracted by wavelet transform, and the wavelet coefficients are processed as input of neural network pattern recognition. When the pattern recognizes that the system is in an island state, it sends an island protection control signal to stop the distributed generation[5-6].

2.2 Principle of Discrete Wavelet Transform

When using a computer to implement wavelet transform, variables can be discretely processed in order to reduce the amount of data. Discrete is mainly to discretize the scale factor a and the translation factor τ, and the discrete wavelet transform is recorded as DWT.

1) Discretization of scale factor

Power level discretization of scales, that is, $a=a_0^m, a_0>0, m\in Z$ The corresponding mother wavelet is:

$$a_0^{\frac{-j}{2}}\psi\left[a_0^j(t-\tau)\right] \qquad j=0,1,2... \tag{1}$$

2) Discretization of displacement factor

Uniform valuesfor τ over the entire time axis. The sampling interval τ satisfies the Nyquist sampling theorem to prevent information loss. Therefore, when m is increased by 1, the scale factor a is doubled, and the corresponding frequency should be reduced by half[3]. So take $a=a_0^j$ When, for one $\tau=ka_0^j\tau_0$ Therefore, the resulting discrete wavelet function is:

$$\psi_{j,k}(t)=a_0^{\frac{-j}{2}}\psi\left[a_0^j(t-ka_0^j\tau_0)\right]=a_0^{\frac{-j}{2}}\psi(a_0^{-j}t-k\tau) \tag{2}$$

The discrete wavelet transform of the function f(t) is defined as:

$$WT_f(j,k)=a_0^{\frac{-j}{2}}\int_{-\infty}^{+\infty}f(t)\psi\left(a_0^{-j}t-k\tau_0\right)dt \tag{3}$$

The reconstruction formula of the inverse transformation is:

$$f(t)=\sum_{j,k}WT_f(j,k)\psi_{j,k}(t) \tag{4}$$

When discretizing a and τ, take $a_0=2, \tau_0=1$ Is the binary dynamic sampling grid. The wavelet function is:

$$\psi_{2^j,k}(t)=2^{\frac{-j}{2}}\psi\left(\frac{t-k}{2^j}\right), \qquad j,k\in Z \tag{5}$$

This wavelet function is called a binary wavelet function. The analysis of the signal by the binary wavelet can zoom in, and as long as the magnification is increased, the small details of the signal can be obtained. By reducing the magnification, you get a coarser signal.

The expression of the binary wavelet transform is:

$$WT_f(2^j,b)=2^{\frac{-j}{2}}\int_R f(t)\overline{\psi}\left(\frac{t-k}{2^{-j}}\right)dt \tag{6}$$

The inverse transform expression is:

$$f(t)=\sum_{j\in Z}\int_R WT_f(2^j,k)\psi_{2^j,k}(t)dk \tag{7}$$

The binary wavelet only discretizes the scale factor, maintains the continuity of the translation factor, and therefore has a time-shifted covariance.

2.3 Overview of Artificial neural network

Artificial neural network (ANN) is based on the basic characteristics of human brain for simulation and Abstraction. ANN is widely used in pattern recognition, automatic control, fault diagnosis and many other fields. In the engineering application of artificial neural network, more than 80% of the neural network models use the Back Pr-opagation (BP) network and its improved form.

2.3.1 Artificial Neural Network Pattern Recognition

Pattern recognition is a technique for studying the discrimination and automatic processing of patterns by mathematical methods and using a computer. The artificial neural network has powerful autonomous learning ability and adaptive characteristics, and divides and discriminates the characteristics of the target. The steps for pattern recognition are as follows.

Sample acquisition: obtaining a sample set for neural network learning training;

Conventional processing: observing, sampling, and acquiring sampling information on the identified object; then processing the sampling information to obtain a sample expression containing useful information;

Feature transformation: On the basis of obtaining the expression of the sample, the sample is processed by the set algorithm to obtain the feature expression of the sample suitable for neural network recognition;

Identification of neural networks: For different research problems and states, select the neural network structure and algorithm appropriate for the problem. Through the use of sample-to-network training, the connection weights between neurons are constantly adjusted, so that the neural network can reflect the nonlinear functional relationship between input and output.

2.3.2 BP Neural Network

The BP neural network is a multi-layer feedforward network with one-way propagation. It is the most widely used model for neural network applications. It uses the learning sample as a feature quantity input network, determines the topology of the network, and corrects it based on the last iteration weight and threshold. Starting from the input layer neurons, through the hidden layer to the output layer, the output of the neurons in each layer is calculated, and the connection weights and thresholds between the layers are adjusted according to predetermined criteria. Then the error is calculated from the output layer to the front layer, and the total error is reduced by adjusting the connection weight and the threshold. The finalized weights and thresholds enable the network to satisfy a highly nonlinear mapping function between input and output.

3. Islanding Detection Technology Based on Wavelet Transform and BP Neural Network

3.1 Principle of Wavelet Analysis Algorithm

At present, wavelet transform mostly uses continuous wavelet transform, discrete wavelet transform and wavelet packet transform to process input signals. Since the discrete wavelet transform algorithm is simple and computationally intensive, the discrete wavelet transform Mallat algorithm is used to realize the transient characteristics [7] of the sampled signal in the island detection. In order to meet the requirements of detection accuracy and rapid detection, the signal sampling frequency of this paper is 10 kHz. According to Shannon's theorem, the fundamental frequency can be decomposed by 7 layers of wavelet.

In this paper, an improved method is proposed. By simultaneously collecting the voltage at the PCC and the output current signal of the inverter, the Daubechies4 wavelet is used to decompose the two signals. Two signal detail components D_{u1}~D_{u7} and D_{i1}~D_{i7} are obtained respectively, and then the root mean square value of the wavelet coefficients is obtained to obtain X_{u1}~X_{u7}, X_{i1}~X_{i7}, a total of 7 signals (X_{u1}-X_{i1})~(X_{u7}~X_{i7}) form a feature vector space and provide it to the neural network. Identification of system working status. The operating parameters of the acquisition system under normal conditions and island conditions, and the square root mean difference of the detail components obtained by using db4 for 7-layer decomposition of current and voltage.

3.2 Structural Design of the Artificial Neural Network

The bp neural network uses a learning method based on the error back propagation algorithm, and its network structure is composed of an input layer, a hidden layer, and an output layer. For the feature vector space in this paper, there are 7 feature quantities, and the neurons of the input layer are set to 7 nodes[8]. Since the island and non-island states of the system can be distinguished by one variable, the number of neurons in the output layer is set to one, and the number of hidden layer nodes is usually selected according to formula (8):

$$l = \sqrt{n + m} + \alpha \quad (8)$$

Among them, l, m, and n are the number of hidden layer nodes, the number of output nodes, and the number of input nodes. α is an empirical constant, and its value is generally between 1 and 10. The results of multiple training tests show that the number of hidden layer nodes is between 10 and 14, with the least number of trainings and the highest recognition accuracy. Therefore, the number of hidden layer nodes in this experiment is 12.

According to the previous analysis, this paper designs the neural network structure diagram shown in Figure 1. The experimental data were used to train the neural network, and the trained neural network was tested. The accuracy of the test was as shown in Table 1.

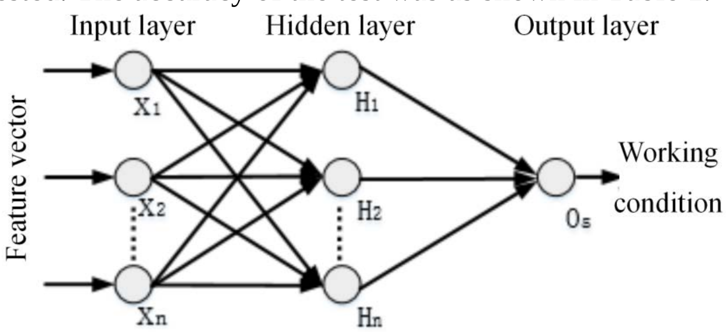


Figure 1 Improved bp neural network structure

Table 1 Neural network test accuracy

Numbering	Types	Number of samples	Recognition result	Accuracy
1	Normal	18	16	88. 9%
	Islanding state	4	4	100%
2	normal	12	11	91. 7%
	Islanding state	3	3	100%
3	Normal	15	15	100%
	Islanding state	6	6	100%
4	Normal	13	12	92. 3%
	Islanding state	5	4	80%
5	Normal	20	20	100%
	Islanding state	4	4	100%

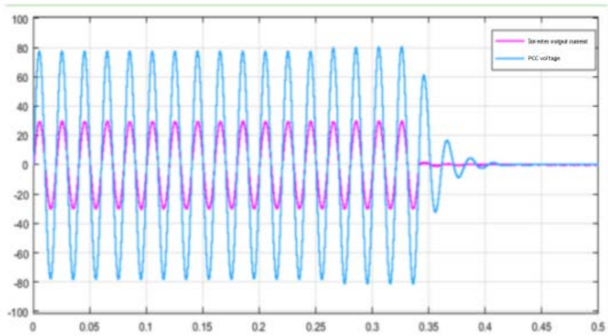
4. Experimental Simulation and Result Analysis

4.1 Experimental Simulation of Single Inverter Grid-connected Island Detection

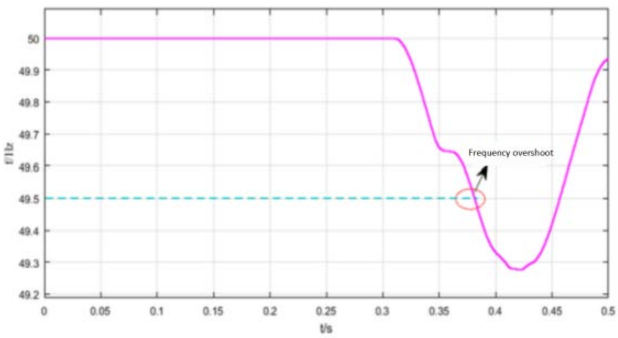
The islanding detection method combining wavelet transform and BP neural network is applied to the system of single inverter grid-connected, and the simulation model is built in MATLAB. The model uses a single-phase inverter, the local load is RLC parallel load, the distributed generation is replaced by 400V DC voltage, and the grid is replaced by 220V/50Hz single-phase voltage. The wavelet transform and neural network processing module can perform 7-layer wavelet decomposition on the voltage and current signals at the PCC, and then obtain the root mean square (RMS) values of the two sets of detail components respectively, and make a difference, and obtain 7 variables to form the feature components. It is used as an input to the BP neural network to identify, where the neural network is a network that has been trained. When the network discrimination system is normal, the output is high level, and the PWM module output pulse controls the operation of the inverter. If the network discriminating system is in an island state, it outputs a low level, and the PWM pulse is blocked to achieve island protection.

The built model is trained and used for island detection. The training process is as follows: (1) The system is divided into two working states, in which state 1 is an island state and state 2 is a non-island state. (2) Set the local load RLC to different sets of different parameters, collect the voltage of the PCC and the inverter output current signal under different parameters, and collect the isolated island and non-island state samples respectively. (3) Perform the wavelet transform on the signal acquired in step (2) and obtain the RMS value of the wavelet coefficient, and subtract the RMS value of the wavelet coefficient of the corresponding current from the root mean square value of the wavelet coefficient to obtain the corresponding eigenvector. Some of the feature vectors are used to train the neural network, and other sets of feature vectors are used to test the island detection effect of the trained neural network. (4) When the neural network is tested, the pattern can be recognized after accurate pattern recognition.

After the neural network is trained, the island detection can be performed in the simulation model. In the simulation model, the parameters of the local load are set to P=3500W, Qc=Ql=2000var, and the system is islanded at 0. 3s. The simulation result is shown in Figure 2.



(a) Voltage and current waveform



(b) Frequency change of voltage at PCC

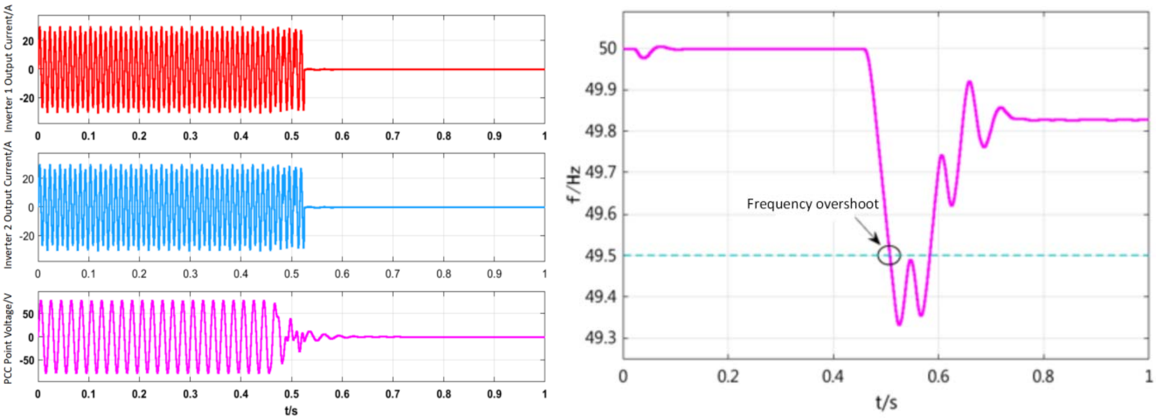
Figure 2 Single inverter island detection simulation graph

Figure 2(a) shows that when the system is isolated at 0. 3s, the inverter output current is reduced to 0. 35s, and the voltage at PCC is reduced to 0 at 0. 42s to achieve island protection. Figure 2(b) shows that the voltage frequency at the PCC exceeds the limit at 0.38 s.

4.2 Experimental Simulation of Multi-inverter Grid-connected Island Detection

In order to verify whether wavelet transform and BP neural network method are applicable to multiple inverters, it is applied in multi-inverter system, and the simulation results are shown in Fig. 3. Figure (a) shows the output current waveform of the inverter and the voltage waveform at the

PCC. The island is set at 0. 3s, and the voltage drop at the PCC is 0 at 0. 6s to achieve a distributed generation shutdown. Figure (b) shows that the voltage frequency at the PCC exceeds 0. 45 s and the occurrence of islands is detected. The detection time is shorter than the active method. The simulation results show that wavelet transform and BP neural network method have a good detection effect on multi-inverter island detection.



(a) Voltage and current waveform (b) Frequency change of voltage at PCC

Figure 3 Multi-inverter island detection simulation graphics

5. Conclusion

Firstly, the basic theory of wavelet transform and BP neural network is introduced. Including continuous wavelet transform, discrete wavelet transform, multi-resolution analysis, neuron model, artificial neural network structure, artificial neural network learning method and learning algorithm and pattern recognition technology based on artificial neural network. Then the principle of the simulation design of the island detection method is analyzed. Including the selection of wavelet transform algorithm, the selection of wavelet master function, the processing of wavelet coefficients, the selection of artificial neural network and its structural design. The simulation experiment of single inverter and multi-inverter grid-connected system is carried out in MATLAB, and the simulation result of islanding detection is obtained. The experimental results show that in the case of multi-inverter grid connection, the active frequency offset method is less affected by the dilution effect and has a faster detection speed.

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