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A novel neural network with simple learning algorithm for islanding phenomenon detection of photovoltaic systems

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ABSTRACT

This study aimed to propose an intelligent islanding phenomenon detection method for a photovoltaic power generation system. First, a PSIM software package was employed to establish a simulation environment of a grid-connected photovoltaic (PV) power generation system. A 516W PV array system formed by Kyocera KC40T photovoltaic modules was used to complete the simulation of the islanding phenomenon detection method. The proposed islanding phenomenon detection technology was based on an extension neural network (ENN), which combined the extension distance of extension theory, as well as the learning, recalling, generalization and parallel computing characteristics of a neural network (NN). The proposed extension neural network was used to distinguish whether the trouble signals at the grid power end were power quality interference or actual islanding operations, in order that the islanding phenomenon detection system could cut off the load correctly and promptly when a real islanding operation occurs. Finally, the feasibility of the proposed intelligent islanding detection technology was verified through simulation results.

1. Introduction

When a photovoltaic power generation system is connected with a grid power system to supply power, and the grid power is cut off due to a malfunction, the photovoltaic power generation system cannot detect the problem and cut the power. This situation results in an independent power supply phenomenon, which is called an islanding operation. Once an islanding operation occurs, a protective device should immediately detect and stop it; otherwise there may be a negative impact on the power supply system or power users (Task, 2002). When an islanding operation occurs, if the gap between the total output power of a photovoltaic power generation system and the total consumed power of the load in the area of the islanding operation exceeds a certain degree, then, the voltage and frequency of the system would change significantly. At this moment, over/under voltage relay (OVR/UVR) and over/under frequency relay (OFR/UFR) can be used for detection to avoid the continuation of the islanding operation; however, when the output and load consumption of a photovoltaic power generation system approach a balance, the changes in voltage and frequency of the system are not sufficient for detection by the voltage and frequency relays; this is called the non-detection zone of relay in this paper (Mango, Liserre, & Aquila, 2006a; Mango, Liserre, & Aquila, 2006b). Therefore, other methods must be used for detection of an islanding operation in order to avoid the phenomenon continuing.

At present, the existing islanding operation detection methods can be divided into passive (IEEE Std. 1547, 2003; Jeraputra & Enjeti, 2004; Jones, Sims, & Imece, 1990; Mango et al., 2006a, 2006b) and active detection modes (Hung, Chang, & Chen, 2003; John, Ye, & Kolwalkar, 2004; Ye, Kolwalkar, Zhang, Du, & Walling, 2004; Ye et al., 2004). The passive detection technique monitors the load end states, such as voltage, frequency, and phase angle to judge whether there is an islanding operation. The passive detection technique mainly includes a voltage phase jump detection method, a frequency change rate detection method, and the third harmonic distortion of a voltage surge detection method (Mango et al., 2006a, 2006b). However, only the third harmonic distortion of a voltage surge detection method lacks a non-detection zone, the other two detection methods have non-detection zones, the size of the non-detection zone depends on the sensitivity of the relay. The non-detection zone is large if the sensitivity of the relay is low, however, the non-detection zone can be reduced if the sensitivity of relay is increased, but a misoperation is likely to occur as a result, which influences the stability of the relay. The sensitivity of the relay should not be set too high, in consideration of the stability of the relay, thus, it is necessary to use an active detection mode together with a passive detection mode in order to remedy the deficiency.

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During ordinary operations, the active detection mode initiatively exerts a periodic disturbance on the voltage or frequency of the system in parallel operation mode. Since the grid power system is a very stable reference supply, the disturbance of the active detection mode does not exert a significant influence on the system voltage or frequency under normal conditions. However, when an islanding operation occurs, the system loses its stable reference power supply, and this disturbance to the active detection mode would cause instability in the system. Even if the power generation output and load consumption are balanced, the disturbance would break the balanced state of power, and the obvious voltage or frequency changes of the system at this point would cause the islanding operation to be detected. The active detection method mainly includes an active voltage drift method, an active frequency drift method, a slip mode frequency shift method, and a load variation method (Ye, Kolwalkar, et al., 2004; Ye, Li, et al., 2004). However, the power system may experience an electrical disturbance from an external force, which would be regarded as an islanding detection. Therefore, this paper adopts an extension neural network (ENN) based multi-variable method that combines passive and active detection modes to detect an islanding operation, where the photovoltaic power generation system can be promptly cut from load when the grid power becomes disconnected, furthermore, it can distinguish whether the trouble signal at the grid end is derived from a power quality disturbance or an actual islanding operation.

2. The proposed extension neural network (ENN)

The extension neural network theory combines the concept of an extension theory with the concept of a neural network, and calculates the relations among various data through the extension distance (ED). Fig. 1 shows the architecture of an extension neural network; it has input and output layer neurons, the input data are first classified in the architecture, and are then read in the extension neural network, the output layer stores the calculated extension distance. The connection between the input layer and the output layer is the weighting factor, which includes the upper limit of the weighting factor, the weighting center, and the lower limit of the weighting factor. Finally the minimum ED value of the output layer of different types is determined, and the type of data is judged (Chao, Li, & Wang, 2009; Wang, 2003).

2.1. Learning process of extension neural network

The extension neural network is of supervised learning, which means first inputting a characteristic sample, if the characteristic sample does not match the preset target value, then, the weighting factor shall be modified, and the accuracy rate of the identification system can be effectively improved by adjusting the weighting factor.

The parameters are defined before learning, first the learning sample is defined by $X = \{X_1, X_2, X_3, \ldots X_{N_p}\}$ and N_p is the total amount of the learning samples, each sample contains the characteristic and type of data $X_i^p = \{x_{i1}^p, x_{i2}^p, x_{i3}^p, \ldots, x_{in}^p\}$, among which $i = 1, 2, 3, \ldots, N_p$, and n is the characteristic number, and p is the type. If N_m is the total number of errors, then, the total error ratio, E_τ can be defined as follows:

$$E_\tau = \frac{N_m}{N_p} \tag{1}$$

The learning rule of an extension neural network is described as follows (Chao et al., 2009; Wang, 2003):

Step 1: Set up extension matter-element model, and set the weighting factor between input and output layers, the kth matter-element model can be expressed as

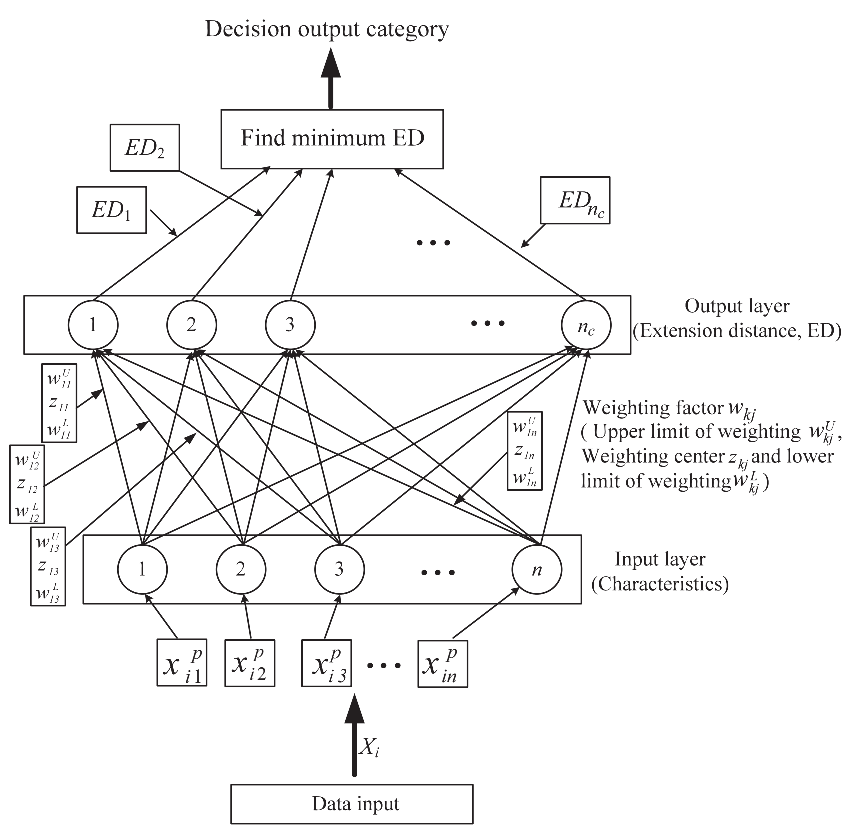

Fig. 1. Extension neural network architecture diagram.