Fault diagnosis of VSG inverter under grid connection

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Abstract. Under different working conditions, the output variable waveform corresponding to the same fault will be different. This article introduces the VSG inverter model under grid connection and verifies the correctness of the model. The three-phase current of the inverter bridge arm is selected as the research object, and the time-domain two-dimensional graph is formed to classify single IGBT and 2 IGBT open circuit faults, and encode various faults feature vector; the deep convolutional neural network is established and the fault diagnosis is performed, and the feature vector is used as the input and the corresponding fault code is the output. The training simulation realizes and verifies the feasibility and accuracy of the fault diagnosis of the VSG inverter using the deep convolutional neural network.

1. Introduction
The inverter is an important interface between distributed power sources and the entire microgrid [1]. Common inverter control methods are: PQ control, VF control and Droop control. PQ controls the output power to remain constant, but it does not have the ability to adjust frequency and voltage. VF control can provide stable frequency and voltage for the system, but it is suitable for off-grid small-capacity inverters and cannot take into account load changes. Although Droop control has the performance of one-time frequency modulation, the output frequency of its controller is sensitive to load fluctuations and its anti-interference ability is relatively weak. The virtual synchronous generator (VSG) technology introduces the moment of inertia and damping coefficient parameters of the synchronous generator into the inverter control, so that the inverter has the ability to regulate voltage and frequency, and improve the frequency dynamics of the inverter. The response characteristics enhance the stability of the inverter system [2]. Related research shows that the inverter power tube switching circuit failure accounts for 82.5% of the entire drive system failure [3]. Once the inverter fails and cannot be found and repaired accordingly, it is very likely that the inverter will be completely destroyed, and even have an impact on the entire power grid, causing unnecessary safety hazards and economic losses [4]. Reference [5] aims at the double-device open-circuit fault, and uses the main component of terminal voltage, the amplitude of the fundamental wave and the second harmonic to form the fault feature vector as the input of the BP neural network classifier. Although the diagnosis is quick, the accuracy is not enough. Therefore, this article adopts deep convolutional neural network for learning and training.
2. Mathematical model and simulation results of virtual synchronous generator

As shown in Figure (1), the DC side voltage is set to 800V, and the right microgrid voltage is 380V. In the grid-connected state, the active power of an impedance before 1s is set to 20000w, and the reactive power is set to 0. After 1s, the system power is set to 30000w, and the reactive power is set to 15000var. Figure (2) can clearly see the active power from 20000w due to the introduction of the moment of inertia, So slowly increase to 30000w, and the reactive power slowly increases from 0 to 15000var. Verify the correctness of the platform.

3. Failure analysis of VSG inverter

If in the grid-connected mode, a single IGBT tube of an inverter fails, because the microgrid AC bus voltage and frequency are clamped by the large grid, only the phase of the fault tube will output fault current, and the other two phases will almost no change.

| Fault type          | Number of failures | Failure performance                                      |
|---------------------|--------------------|----------------------------------------------------------|
| Single tube failure | 6 kinds            | There is a pipe open circuit, and there are two obvious characteristics: 1. The output |
Current of this phase will lose half a cycle.  
2. During the loss of half cycle the other two phases are balanced and the three-phase current vector sum is zero.,

| Failure of two tubes on the same side of the bridge arm | 6 kinds |
| Two tube failures of crossed bridge arms | 6 kinds |
| Two power tubes of a phase bridge arm are faulty | 6 kinds |

In addition to affecting the phase in which it is located, it also causes the third-phase phase current to fail to commutate, resulting in missing positive or negative half-cycle waveforms.,

When the two crossing tubes fail, it will cause the phase current of the bridge arm where it is located to lose the corresponding half cycle, and the upper and lower waveforms third phase current are distorted.

When the two tubes of the same-phase bridge arm fail: This phase will lose the upper and lower waveforms at the same time, the current value is about 0;

From Table 1, we can conclude that the fault waveforms are divided into four major categories and 24 small categories. The following simulation images are made by analyzing these fault characteristics in Figure 3.
From the top left to the bottom right in the figure are the three-phase current waveform diagrams of single tube, double tube at the same end, double tube in phase, and double tube crossed respectively when a fault occurs in 0.2s.

4. Deep convolutional neural network structure and fault diagnosis results

4.1 AlexNet network structure
AlexNet network consisting of 5 convolutional layers and 3 fully connected layers, with a total depth of 8 layers. It is the first model that introduces convolutional neural networks into the field of computer vision and achieves breakthrough results. Using the ReLU activation function, there are a total of 60 million parameters. The greatest contribution of AlexNet is to prove the ability of deep learning. At the same time, with the help of GPU, the results of training can be obtained within an acceptable time range, which promotes the development of convolutional neural networks and even deep learning.

4.2 Fault diagnosis result
Through analysis, simulation is carried out as above. The formed time-domain two-dimensional graph is used as the fault feature vector, and the fault feature vector is put into the AlexNet network for learning and training.

Through simulation, we got 15 groups of classifications. Each group of 90 samples, all of which are input into the AlexNet network as the features, and the number of iterations is ten. Choose 80% as the training sample and 20% as the test sample. The operating environment is Intel(R)Core(TM)i5-9400F with 8G memory. As shown in the figure, the accuracy rate is 98.89% and the loss rate is 1.11%. Verify the feasibility and correctness of the method.

5. Conclusion
With the rise of microgrid, virtual synchronous generator technology has inertia and damping. The main circuit of the inverter is prone to open circuit failure. The specific work of this paper is as follows:

Firstly, analyze the inertia mathematical model of the synchronous generator, introduce it into the inverter, and establish a VSG model under grid connection. And verified the correctness of the model.

Classify the types of faults caused by different IGBT open circuits, and analyze the causes and types of fault waveforms. And simulate the faulty three-phase current waveform.

AlexNet network in deep convolutional neural network is introduced. And put the classified fault waveforms into the neural network for training and learning. Finally, the accuracy function curve is obtained to prove the correctness and feasibility of the experiment. At the same time, it provides a strong scientific basis for fault diagnosis of VSG inverters under grid connection.
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