A short circuit fault diagnosis method for DC voltage converter based on neural network

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Abstract. Aiming at the problem of complicated data calculation and slow data iteration in the diagnosis process of the traditional wavelet packet decomposition method for DC voltage converter short circuit fault diagnosis, a short circuit fault diagnosis method based on neural network is proposed. After determining which phase has a short circuit, the MMC method is used to locate the specific short circuit fault position. The basic structure of the neural network is determined according to the needs of short circuit fault diagnosis of the converter, and the training sample set is used to train the neural network and determine its parameters. Combined with fault location and fault characteristics, the short circuit fault diagnosis of the converter is completed by using neural network. By comparing with the short circuit fault diagnosis method based on wavelet packet decomposition, it is proved that the proposed short circuit fault diagnosis method based on neural network can complete several iterations in a short time and realize the high efficiency of fault diagnosis.

1. Introduction
With the development of society and economy, people pay more and more attention to ecology and energy, and DC voltage converter is more and more widely used. The output voltage of some DC voltage converters has the same reference point as the input voltage, while the output voltage of some DC voltage converters is isolated from the input voltage. DC voltage converter is widely used in aviation, new energy and other systems, and its rapid fault diagnosis can effectively improve the reliability of the whole system [1]. Once the DC voltage converter fails, if the fault is not isolated in time, the whole system may collapse. Therefore, one of the important measures to solve this problem is to use the diagnostic method with high accuracy and high diagnostic efficiency. The traditional short-circuit fault method based on wavelet packet decomposition can correctly diagnose the fault type. However, due to the complexity of data calculation in wavelet packet decomposition, each fault diagnosis needs data iteration again, resulting in low diagnostic efficiency.

Neural network is an algorithm mathematical model that simulates the behavior characteristics of animal neural network and carries out distributed parallel information processing. This kind of network, depending on the complexity of the system, can achieve the purpose of information processing by adjusting the interconnection between a large number of internal nodes [2]. Based on the above analysis, this paper will design a short-circuit fault diagnosis method for DC voltage converter based on neural network. The following is the specific content.
2. Design of short circuit fault diagnosis method for DC voltage converter based on neural network

The short circuit fault diagnosis method of DC voltage converter based on neural network designed in this paper firstly uses Kalman algorithm to process the output voltage of DC voltage converter to determine which phase has short circuit. Using MMC method, locate the specific location of short circuit fault. The establishment of the neural network structure was determined, training samples were used to train the neural network, and the diagnosis of DC voltage converter short circuit fault was completed.

2.1 Short circuit fault location of voltage converter

In order to further determine the specific location of the DC voltage converter short-circuit fault, MMC was used to locate the fault. With the diagram of the internal circuit diagram of the DC voltage converter as the illustration object, the MMC is used to locate the short circuit fault in detail.

![Figure 1. Internal circuit diagram of DC voltage converter](image)

The expression of internal switching fault function \( S \) of DC voltage converter is defined as follows:

\[
S = \begin{cases} 
1 & \text{upper pipe is on, lower pipe is short circuit} \\
0 & \text{lower pipe on, upper pipe short circuit} 
\end{cases}
\]  

(1)

When the DC voltage converter works normally, the output voltage of the converter is expressed as \( v_c = S \cdot v_{sm} \), where \( v_{sm} \) is the voltage of the triode [3]. If there is a short circuit fault in the T1 tube, the output of the DC voltage converter will be:

\[
v_c = \begin{cases} 
S \cdot v_{sm} & i > 0 \\
0 & i < 0 
\end{cases}
\]  

(2)

If a short circuit fault occurs in the T2 tube, the output of the DC voltage converter will be:

\[
v_c = \begin{cases} 
v_{sm} & i > 0 \\
S \cdot v_{sm} & i < 0 
\end{cases}
\]  

(3)

If the T1 and T2 tubes are short-circuited at the same time, the output of the DC voltage converter will be:

\[
v_c = \begin{cases} 
v_{sm} & i > 0 \\
0 & i < 0 
\end{cases}
\]  

(4)

Similarly, according to the relationship between voltage and power, it can be analyzed that when the current polarity of the bridge arm inside the converter is positive, the power flowing through the sub-module under the condition of T1 tube fault is equal to that under normal circumstances. When the current polarity of the bridge arm is negative, the power flowing through the sub-module under the fault condition of T1 tube is 0. That is to say, when there is a short circuit fault, the power flowing through the fault will be greater than the power in normal operation. It can be found from the analysis of capacitance that the nearest capacitor connected to the short-circuit fault will switch at high
frequency in the two states of short-circuit and charging, in which case the voltage drop of capacitor is rapid and the amplitude is small [4]. Selected out from the bridge arm all capacitance voltage low will work with the other voltage of bridge arm compared with the minimum value, when a certain part of the DC voltage converter voltage value and the minimum were difference more than the threshold value $\Delta V_c$ of the voltage i, and sustained a voltage level transformation period t, the part is to determine the fault happened.

2.2 Establishment and training of neural network

According to the requirement of fault diagnosis of DC voltage converter, forward feedback BP neural network with input layer, hidden layer and output layer is adopted. The neurons in each layer are connected to the neurons in the upper layer according to the connection threshold. The number of input nodes of BP neural network is the same as the reason of short-circuit fault of DC voltage converter [5]. The number of output nodes of BP neural network is the same as the number of input nodes. The number of hidden layer nodes is calculated according to the formula below.

$$y = \sqrt{n+m+\delta} \quad (5)$$

In formula (5), y is the number of nodes in the hidden layer of the neural network, n is the number of nodes in the input, m is the number of nodes in the output, and $\delta$ is the parameter after fault feature extraction. As shown in the following figure, the training sample is used to complete the training of neural network according to the process in the figure.

![BP neural network training flow chart](image)

Figure 2. BP neural network training flow chart

After the training sample is normalized, the mean square error is calculated at the input node of the neural network, and the error is minimized by iterative calculation [6]. For the JTH output node corresponding to the ith input node, the error calculation formula between input and output is as follows.

$$\sigma \approx \frac{\sum_{j=1}^{n} \left( \sum_{i=1}^{s} \left( t_{ij} - a_{ij}^{s} \right)^2 \right)}{ns^2} \quad (6)$$

In formula (6), n is the total number of samples in the training sample set; $t_{ij}$ represents the expected output value of training in group s, and $a_{ij}$ represents the actual output value. According to the calculated mean square error, the connection weights of the three layers of the neural network are modified according to the following formula.
In formula (7), \( x_i \) is the input layer node of the neural network, \( w_{ij} \) is the connection weight of nodes in the hidden layer, \( h_j \) is the connection weight of the input layer and the hidden layer, \( \Theta_j \) is the threshold value, \( v_{jl} \) is the connection weight of nodes in the output layer, \( g_l \) is the connection weight between the hidden layer and the output layer, and \( \gamma_l \) is the threshold value. According to the above formula, weights and thresholds are modified to complete the second stage of neural network training. Repeat the above two processes repeatedly through iteration until the training objective is achieved. After the training of BP neural network, the fault diagnosis of DC voltage converter is realized by combining with the short-circuit fault location results.

2.3 Implementation of fault diagnosis

After locating the short-circuit fault position of DC voltage converter, BP neural network after training is used to judge the cause of the fault, so as to diagnose the short-circuit fault of DC voltage converter. The following figure shows the output voltage signal waveform of each component when the DC voltage converter is in operation and when short-circuit fault occurs. After the signal input is processed by Fourier transform, it is input to the input end of the neural network. After processing in the neural network, the cause of fault is determined and fault diagnosis is realized.

![Figure 3. Output voltage signal waveform of each component of DC voltage converter](image)

In figure 3, \( S \) is the driving signal of the voltage converter switch tube, \( U \) is the voltage signal of the converter auxiliary coil, as well as the input voltage of the DC voltage converter, \( C \) is the output voltage signal of the converter capacitor, \( D \) is the output voltage signal of the diode, and \( T \) is the output voltage of the emitter of the triode. It can be seen from the waveform information in the figure that the voltage at both ends of the auxiliary coil remains unchanged when short-circuit faults occur in different components. The diode will have voltage zero due to high voltage in short circuit, and then reverse breakdown recovery voltage. When the transistor appears voltage, emitter voltage set 0, the transistor does not work, and the circuit output voltage without any change. The trained neural network iterates over the input voltage signal. According to the different input nodes, the specific fault components in the DC voltage converter are determined after the iteration, and the short-circuit fault diagnosis of the DC voltage converter based on the neural network is completed.
3. Experiment
In order to verify this method, this section adopts the comparative experiment method to draw the corresponding conclusion and complete the experimental verification by comparing it with the traditional DC voltage converter short-circuit fault diagnosis method.

3.1 Experiment to prepare
The experiment was conducted on two computers with identical configurations. The hardware and software configurations of the experimental computers are shown in table 1 below.

| Table 1. Experimental computer hardware and software configuration | configuration |
|---------------------------------------------------------------|---------------|
| project            | configuration                  |
| CPU                | Intel(R) Core (TM) i7-3750 3.75GHz |
| hard disk          | mechanical 500G               |
| memory             | 16G                         |
| graphics chips     | NVIDIA                     |
| memory capacity    | 4GB                        |
| Ethernet card      | Realtek PCIe GBE Family Controller |
| switches           | Mbps                       |
| operating system   | Windows 10                |

After configuring the experimental computer, prepare the experimental equipment according to the list of experimental equipment in table 2. Among them, 20 groups of experimental DC voltage converters should meet the requirements of different parameters such as rated voltage and different voltage transformation range to avoid experimental errors.

| Table 2. List of experimental equipment | quantity |
|----------------------------------------|----------|
| experiment equipment                   | 2        |
| DC voltage converter for experiment    | 20       |
| 5v DC power supply                     | 2        |
| 10 v DC power supply                   | 2        |
| 100 v DC power supply                  | 2        |
| 220 v DC power supply                  | 2        |
| multimeter                             | 2        |
| conductor                               | a number of quantity |

3.2 Experiment content
Record all DC voltage converter voltage conversion range, use wire short circuit converter internal elements, or use the burn through components to replace normal components, or directly to implement circuit short circuit directly on both ends of the converter, the DC voltage converter in different types of short circuit fault, and using a multimeter to investigate whether a fault. Taking the short-circuit fault diagnosis method of DC voltage converter based on neural network proposed in this paper as the experimental group and the traditional short-circuit fault diagnosis method based on wavelet packet decomposition as the reference group, the number of data iterations in the same time when two groups of methods are selected for fault diagnosis by comparing the indicators. In the same time, the more data iterations, the more reliable the method is, and the higher the diagnostic efficiency and accuracy.

3.3 Experimental results
The experimental results are shown in the figure below. The information in the figure is analyzed to draw the experimental conclusion.
Figure 4. Experimental results

It can be seen from FIG. 4 that within the same experimental period, the number of data iterations of the DC voltage converter short-circuit fault diagnosis method in the experimental group was significantly higher than that in the reference group. The number of iterations in the initial fault diagnosis of the experimental group was higher than 10, while the number of iterations in the initial fault diagnosis of the reference group was far lower than 10. In the later stage of diagnosing the short-circuit fault of DC voltage converter by two groups of fault diagnosis methods, the number of iterations of the two groups of fault diagnosis methods was stable, but the number of iterations of the experimental group was about 5 times that of the reference group. It shows that the same reference group fault diagnosis method, the experimental group diagnosis method can be repeated in the same time. To sum up, the fault diagnosis method of DC voltage converter based on neural network proposed in this paper can complete multiple data iterations in a short time, so as to realize fault diagnosis with high accuracy and efficiency, which has a better development prospect.

4. Conclusion
The normal operation of DC voltage converter is related to the safe operation of the whole system. In this paper, a fault diagnosis method based on neural network for DC voltage converters is proposed, which can complete and maintain multiple data iterations in a short time and achieve high efficiency and accurate fault diagnosis by taking advantage of the good adaptability and self-learning habits of neural network. Compared with the traditional wavelet packet decomposition fault diagnosis method, the proposed method is proved to be superior.

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