Research on Fault Diagnosis Model of Transmission Line under Lightning Stroke Based on Neural Network

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Abstract—Transmission lines are an important part of the power system. In recent years, there have been more and more lightning trips, power outages and outages, which have become one of the hazards that threaten the stable operation of the power grid, and seriously endanger the reliability of the power grid operation. It is necessary to diagnose problems with transmission line faults. In this paper, after the information generated by the fault is processed by wavelet, it is input into the neural network fault diagnosis model as the input part, and the fault type of the transmission line is predicted and identified by the neural network operation, and the experiment is carried out through MATLAB simulation software. The prediction results show that the model is more accurate in fault diagnosis of transmission lines.

1. INTRODUCTION

The transmission line is an important part of the power system, which accounts for the largest proportion of the grid structure, and is also the component with the most failures in the grid\textsuperscript{[1]}. Most domestic blackouts are caused by line faults. Every transmission line failure will cause damage to insulators, wires and other facilities in addition to impacts on the system, leaving hidden safety hazards to system operation\textsuperscript{[2]}. In recent years, as far as the State Grid is concerned, there have been more and more lightning trips, power outages and outages, which have become one of the dangerous sources that threaten the stable operation of the power grid\textsuperscript{[3]}. Therefore, the rapid diagnosis of transmission line faults under lightning strikes has important economic value and practical significance.

The research of domestic and foreign scholars on the fault diagnosis of transmission line system is mainly divided into the identification of short-circuit characteristics, identification of transformer fault information, identification of frequency oscillations, identification of fault types, and identification of power quality. Literature [4-5] proposes that the fault information is processed by wavelet and combined with neural network preprocessing, and the output of the wavelet neural network with different functions is constructed, and then different types of short-circuit faults can be distinguished and identified. Literature [6-7] studies the fault gas when the transformer has a fault, and uses neural networks to identify and analyze the type of fault. Literature [8-10] uses wavelet neural network for training and learning to realize the protection of the transmission system, and more quickly, accurately,
and efficiently identify line oscillations and faults. Literature [11-13] uses wavelet analysis for eigenvalue input to analyze the potential eigenvalues, analyzes the BP neural network from the time domain, frequency domain, and amplitude to distinguish and predict power quality.

In order to improve the accuracy of transmission line fault diagnosis under lightning strike conditions, and to further strengthen the research of transmission line fault diagnosis technology, in this paper, neural network is used to train the fault diagnosis model of transmission lines under lightning strikes, and through the analysis of examples of power line sudden faults caused by lightning strikes, the diagnosis and early warning of power line sudden faults caused by lightning strikes are realized.

2. Transmission Line Fault Analysis Under Lightning Strike Conditions

2.1 Short Circuit Fault of Transmission Line

Short-circuit is a common type of fault with a high probability of occurrence in power systems[14]. Short-circuits in transmission lines may be caused by external forces, or they may be grounded by physical effects. The short circuit causes the current to be led into the ground, forming zero sequence current and zero sequence voltage, which in turn affects the safe operation of the line[15].

\[ u_m = u_{mff} + u_{mf} \]
\[ i_m = i_{mff} + i_{mf} \]

After a short-circuit fault occurs, its transmission line characteristics are shown in Table 1.

| Fault type          | symbol | Comparison of faulty components and non-faulty components |
|---------------------|--------|----------------------------------------------------------|
| Singlephase ground  | f^{(1)}| 1.4-2.6 times                                           |
| Two shorts          | f^{(2)}| no big difference                                         |
| Two ground shorts   | f^{(3)}| 1.4-2.6 times                                           |
| Three short circuit | f^{(3)}| Big difference between maximum and minimum               |

2.2 Mathematical Model of Transmission Line

2.2.1 Single π model

The single π model is based on the R-L model, and the equivalent capacitance C is connected in parallel at both ends to establish a single π model. The differential equation is:
The differential equation is:

\[ u_{mn}(t) = Ri_{mn}(t) + L \frac{di_{mn}}{dt}(t) \]  

(3)

\[ i_{mn}(t) = i_{mn}(t) + C \frac{di_{mn}}{dt}(t) \]  

(4)

2.2.2 Distributed parameter model

There are many differences between the distributed parameter model and the concentrated parameter model of the transmission line. The current \( i \) and voltage \( u \) at any point on the transmission line form a mathematical relationship with time \( t \) and length \( x \), which is a process caused by electromagnetic wave extension.

The differential equation is:

\[ -\frac{\partial i(x,t)}{\partial x} = G_0 v(x,t) + C_0 \frac{\partial v(x,t)}{\partial t} \]  

(5)

\[ -\frac{\partial v(x,t)}{\partial x} = R_0 i(x,t) + L_0 \frac{\partial i(x,t)}{\partial t} \]  

(6)

2.3 Fault identification under lightning strike conditions

Based on the research of literature [17], there are characteristic differences in the time-domain waveforms of transient traveling wave signals: when a non-fault lightning strikes, the transient current waveform is approximately symmetrical on an axis parallel to the zero axis; when a fault occurs, The waveform is generally monotonic[18]. Integrate the transient waveform above and below the zero axis.

\[ I_+ = \int_0^{0+} i_+(t) dt \]  

(7)

\[ I_- = \int_0^{0+} |i_-(t)| dt \]  

(8)

In order to distinguish the characteristics of the transient current waveform during lightning strike interference and fault, the waveform characteristic quantity \( \varepsilon \) is extracted as follows:

\[ \varepsilon = \frac{I_+ - I_-}{I_+ + I_-} \]  

(9)

The value of the time-domain waveform characteristic value of the transient current during the above non-fault lightning strike, lightning strike fault and short circuit fault is shown in Table 2:
The data of AB two-phase short circuit table 2 shows that the characteristic quantity of transient waveform during non-faulty lightning strike is relatively small, while the characteristic quantity of transient waveform under lightning fault and short-circuit conditions is relatively much larger. In the case of a fault, the transient waveform characteristic value is close to 1, and in special cases it may be 1. The waveform characteristic value of a non-fault lightning strike is obviously not an order of magnitude compared with that of a fault. Based on this, the identification criterion of non-faulty lightning strike can be constructed, as follows:

$$\varepsilon < \varepsilon_0$$  \hspace{1cm} (10)

In the formula, $\varepsilon_0$ is the set threshold. A large number of test results show that $\varepsilon_0 = 0.5$ is more appropriate. When $\varepsilon < \varepsilon_0$, it is judged as a non-faulty lightning strike; otherwise, it is judged as a fault.

3. **Research on Fault Diagnosis Model of Transmission Line Under Lightning Strike Based on Neural Network**

3.1 **Flow chart of fault diagnosis model for transmission line**

In the power system, the information generated by the failure of the transmission line is much and very complicated. It is particularly important to judge the type of the fault signal on time and efficiently. After the fault transient characteristic value is processed by wavelet, it is used as the input part of the transmission line fault diagnosis system to identify various transmission line fault types. The flow chart of the specific transmission line fault diagnosis model is as follows:

![Flow chart of fault diagnosis model for transmission line](image)

3.2 **Wavelet packet analysis**

The basic algorithm of wavelet packet analysis is to pre-solve the wavelet in the high frequency band and decompose it into the corresponding high frequency and low frequency parts to solve the problem[19]. Hierarchical division is a more precise and accurate data signal processing and analysis method. The wavelet packet transform method is used to analyze the characteristics of the signal, and
then select the corresponding frequency interval to match the frequency spectrum in the corresponding signal, which enhances the resolution of frequency band analysis.

The extraction of each energy spectrum value of the initial fault information requires the following points: first sample the electrical quantity of the fault information, and sample the fault information according to the Shannon sampling theorem rule, try to avoid the superposition and leakage of the frequency band of the fault information; Three-layer wavelet packet decomposition and reconstruction are performed on the fault information, and the wavelet packet coefficients of each frequency band are extracted respectively; finally, the energy value of the frequency band is obtained by transformation.

3.3 BP neural network

The principle of the neural network prediction model is to use multiple nonlinear function transformations to fit the unknown relationship between input data and output data. When learning unknown relationships with historical data, more historical data is needed to have a better fitting effect[20].

Nowadays, the error back propagation neural network or BP neural network is one of the most widely used neural network models. Its structure is simple, the simulation ability is strong, and it is easy to implement. In recent years, it has been widely used in the field of evaluation and prediction. BP neural network includes 3 or more neural networks including input layer, intermediate layer (hidden layer) and output layer.

For the input layer neuron, its output is the same as the input. The operating characteristics of the neurons in the middle hidden layer and the output layer are expressed as:

$$a_i = \sum_{j=1}^{n} w_{ij} o_j$$

$$o_j = f(a_j)$$

Among them, $w_{ij}$ is the connection strength of the synapse between the neuron $u_i$ and $u_j$, called the connection weight; $a_i$ is the weighted sum of the input of the neuron $u_i$, indicating the activity degree of the neuron; $o_i$ indicates its output.

For output layer neurons:

$$o_i^p = f'(a_i^p) \cdot (t_i^p - o_i^p)$$

In the formula, $t_i^p - o_i^p$ reflects the output error of the neuron $u_i$ of the output layer, and $f'(a_i^p)$ is used as a scale factor for the output error, which dynamically affects the error correction amount according to the active value of the neuron $u_i$.

The following figure shows the process of applying BP neural network to fault diagnosis of transmission lines under lightning strike conditions.
Given energy eigenvalue input vector and fault result output vector
Find the output of each unit in the hidden layer and output layer
Find the deviation between the target value and the actual output e

\( \text{\textbf{e meet the requirements?}} \) End

Calculate the hidden layer unit error
Find the error gradient
Weight learning

**YES**

**NO**

**Fig. 5 Application of BP neural network to the process of fault diagnosis of transmission line under lightning conditions**

**4. SIMULATION ANALYSIS**

By calling the wavelet transform toolbox in MATLAB, using a three-layer wavelet packet to decompose the fault information into values with 8 frequency bands, and then calculate the energy eigenvalues of the wavelet coefficients in each frequency band to obtain the low frequency and high frequency. The energy value of the node; finally, the calculated energy characteristic value is used as the input of the BP neural network.

Constructed with a single hidden layer of the BP network, using Sigmoid as the activation function, the number of neurons in the input layer is 24, and the output layer is represented as the faulty line of the transmission line system. The minimum training error is set to 0.001 and the maximum number of iterations is 1000. The learning degree is 0.01.

After adjusting the various parameters of the simulation model, perform wavelet packet three-layer decomposition and calculation analysis on the collected zero-sequence current of the faulty line to obtain a total of 80 sets of test data samples. The test results are shown in Table 3.

| Fault type | Number of test samples | Fault line | Output       |
|------------|------------------------|------------|--------------|
| AG         | 20                     | 1          | (1 0 0)      |
| BG         | 20                     | 2          | (0 1 0)      |
| ABG        | 20                     | 3          | (0 0 1)      |
| ABC        | 20                     | 2          | (0 1 0)      |

Substitute 80 sets of test data into the MATLAB simulation program for simulation, and finally get the training model and curve as shown in Figure 6.
Through the analysis of the BP neural network simulation experiment, it is concluded that the BP neural network basically meets the requirements of error accuracy, the recognition rate of the BP neural network is about 80%, and the training result is relatively ideal, but the number of iterations required during training is more. The time required for simulation is also relatively long.

5. CONCLUSION
Transmission lines are an important part of the power system. In recent years, there have been more and more lightning trips, power outages and outages, which have become one of the sources of danger that threaten the stable operation of the power grid, seriously endanger the reliability of the power grid operation, and lead to the paralysis of the entire grid system, causing very large economic losses. Therefore, it is necessary to study the fault diagnosis of transmission lines under lightning strikes. In this paper, the information generated by the fault is processed by wavelet, and is input into the neural network fault diagnosis model as the input part. The neural network operation predicts and recognizes the fault type of the transmission line, and conducts experiments through MATLAB simulation software. The prediction results show that the model is more accurate in the identification of transmission line faults.

Although the accuracy of the BP neural network can reach the expected goal, in actual operation, the BP neural network is prone to local extreme problems, and the slow convergence of the algorithm may cause dimensional disasters. Therefore, the next research direction is to find more effective optimization algorithms to speed up the operation and further improve the fault recognition rate.

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