Research on Mathematical Model of Corona Current Variation Based on Curve Fitting of Computer Neural Network

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Abstract. There will be corona discharge in the transmission line, which will cause process power loss and even interfere with the power grid. At present, the mathematical models for analyzing the variation of corona current can not fit the current waveform under any test conditions effectively. Based on this, this paper first analyzes the fitting principle of corona current mathematical model, and then studies the curve fitting process and results of corona current change based on CNN.

Keywords: Mathematical Model, Corona Current Variation, Curve Fitting, CNN

1. Introduction
With the iterative development of AI tech represented by CNN, it has been widely and deeply applied in many fields, especially in power system [1]. In the UHV transmission line, there will be corona discharge phenomenon, which will cause process power loss and even interfere with the power grid. In order to reduce the adverse impact of corona current discharge on power grid, it is necessary to conduct in-depth analysis and research on the variation characteristics of corona current, so as to realize the real-time monitoring of electromagnetic interference and state of power grid lines. It is necessary to establish an effective mathematical model to study the variation of corona current, so as to realize the effective analysis of its electromagnetic radiation characteristics and denoising.

At present, there are many kinds of mathematical models to analyze the variation of corona current. Among them, there are not only the function of fitting the waveform of steep rising edge and gentle falling edge, but also the function of fitting typical current waveform, as shown in Figure 1 below. However, there are still many shortcomings and problems in these function models, such as the analysis results are not accurate enough, or there is a certain one-sided, which leads to the failure to effectively fit the current waveform under any test conditions [2]. Moreover, these models are too complex to solve the corona current parameters, so it is necessary to build a more effective mathematical model to achieve more effective fitting of corona current changes.
Polynomial

Gauss function

Double exponential function

Figure 1. Mathematical model for analysis of corona current variation.

In addition, with the iterative development of CNN tech, its application in the mathematical model of corona current variation can realize the approximation of various accuracy to any function [3]. In order to avoid the possible corona discharge and reduce the potential safety hazard and energy loss, it is necessary to monitor the corona discharge radiation signal effectively with the help of CNN according to the typical characteristics of corona discharge, such as strong randomness, great influence by environmental factors, and dynamic changes of discharge frequency, amplitude, duration and other waveform parameters. By fitting the mathematical model of corona current based on neural network model, the weights and threshold parameters of the network can be extracted, and finally the mathematical model of corona current can be obtained, so as to lay the foundation for the follow-up research. Therefore, it is of great practical value to study the mathematical model of corona current variation based on curve fitting of CNN.

2. Fitting principle of mathematical model of corona current

2.1. BP neural network model of corona current

BP neural network using error back propagation training algorithm is a kind of multilayer feed forward network with hidden layer, which can systematically solve the learning problem of implicit unit connection weight in multilayer network [4]. BP neural network is used in function approximation, pattern recognition and data compression. The S-type function is used as the hidden layer transfer function and the linear transfer function is used as the output layer. The network structure of the neuron is shown in Figure 2 below. Based on the network, any corona current waveform can be fitted.

Figure 2. The network structure of the BPNN neuron.

The excitation function of implicit element is generally S-function, as shown in the following formula 1, and the excitation function of output unit is generally S-function or linear function, as shown in equation 2 below.
In the aspect of model performance of BPNN neurons, the sum of error squares or the sum of error squares should be used:

\[ E = \frac{1}{2} \sum_{i=1}^{p} \sum_{j=1}^{q} (T_{ij} - O_{ij})^2 \]  

(3)

In which, \( L \) is the output of several neurons. Secondly, for the fitting of corona current waveform, the extraction of its mathematical model needs to construct the BPNN model architecture and determine the number of neurons in the input layer and output layer. Then set the parameters of BPNN network, mainly including the main contents as shown in Figure 3, so as to realize the training of network. In addition, after the training of BPNN network, it is necessary to build the mathematical relationship between the corona current intensity and time parameters based on the specific algorithm, so as to establish the mathematical model of corona current.

2.2. The neural network calibration model

The neural network training algorithm used was a back-propagation function, which updates the weight and bias values according to Levenberg-Marquardt optimization method. The LMA provides a numerical solution to the problem of minimizing generally nonlinear over space of parameters of the function [5]. The applications of the LMA is by given a set of empirical data pairs of independent, to make the sum of the squares of the deviations becomes minimal.

The proposed neural network calibration model is verified by test data, which is not used in the training process. Neural network calibration model can give very accurate results, and it is independent of the angle between image plane and object plane. This fast and accurate calibration method will greatly facilitate the application. The threshold of a single neuron in the output layer is independent of the current waveform to be fitted, and the current extracted by BPNN is fitted.

2.3. Learning method of neural network model for corona current

As one of the main learning methods of corona current neural network model, online learning updates the network weights one by one for each mode pair in the training set, and adjusts the network weights according to the error requirements [6]. Under the new weight, another sample is given, and then the weight is adjusted according to the error requirements until the error under the action of all samples meets the requirements, as shown in the following formula:
\[ w_j(k + 1) = w_j(k) + \eta \delta_j \alpha_j \] (4)

This learning method needs a small storage unit, but it will increase the output error of the network, so it needs to use a smaller learning factor, so that the overall change of the weight of each mode in the training set decreases rapidly after training. This learning method needs a small storage unit, but it will increase the output error of the network, so it needs to use a smaller learning factor, so that the overall change of the weight of each mode in the training set decreases rapidly after training. As another main learning method, batch learning mainly uses the patterns in the training set to train the network, accumulate the weights and revise the weights uniformly:

\[ w_j(k + 1) = w_j(k) + \eta \sum_{p=1}^{N} \delta_j^{p} \alpha_j^{p} \] (5)

This learning method can make the weight drop faster, so it has faster learning speed. In addition, in the process of training, it is necessary to batch process the training mode.

3. Curve fitting of corona current variation based on CNN

3.1. Corona current waveform fitting based on neural network mathematical model

Based on the neural network mathematical model, the double exponential function is used to fit the corona current waveform. In the process of fitting corona current waveform, neural network can achieve high precision approximation of corona current waveform. With the continuous growth of the number of neurons, the corona current waveform can be well fitted. Secondly, the fitting curve of current waveform is selected and compared with the fitting corona current; the fitting curve of positive corona has better fitting effect. In addition, through the analysis of current waveform fitting results, it can be seen that the fitting accuracy is high and the error is small, as shown in Table 1 below.

| Number of neurons | Positive corona | Negative corona |
|-------------------|-----------------|-----------------|
| 5                 | 8.1231×10⁻⁴     | 9.8963×10⁻⁴     |
| 10                | 6.0742×10⁻⁴     | 7.7276×10⁻⁵     |
| 15                | 1.2078×10⁻⁴     | 1.6809×10⁻⁵     |
| 25                | 7.2462×10⁻⁵     | 2.1402×10⁻⁴     |
| 35                | 5.8902×10⁻⁵     | 6.9723×10⁻⁵     |
| 45                | 8.9043×10⁻⁵     | 4.0038×10⁻⁵     |

3.2. Fitting of corona current waveform based on computer mathematical function model

In the process of corona current change in power grid, such as in the process of partial discharge of defects, the electromagnetic radiation signal generated by the discharge at the defect is collected by the sensor, and the signal is normalized. Secondly, based on the experimental test of the source signal, the final waveform of the discharge source signal at the defect is determined. In addition, the fourth and third order Gaussian functions are used to describe the corona discharge current. By fitting the corona current waveform of pulse characteristics, the neural network mathematical model of current is obtained, and the fitting results are shown in Table 2. From the fitting results, it can be seen that the high-precision fitting of corona current only needs a few neurons, and with the increase of the number of neurons, the accuracy of corona current waveform fitting is better and gradually close to the full fitting.
Table 2. Current fitting of neural network mathematical model.

| Number of neurons | Positive discharge | Negative discharge |
|-------------------|--------------------|--------------------|
| 3                 | $5.7202 \times 10^{-4}$ | $5.9860 \times 10^{-4}$ |
| 5                 | $7.8081 \times 10^{-5}$ | $6.0907 \times 10^{-5}$ |
| 7                 | $4.4602 \times 10^{-5}$ | $3.4011 \times 10^{-5}$ |
| 9                 | $1.9093 \times 10^{-5}$ | $4.7391 \times 10^{-5}$ |

3.3. Fitting of arbitrary corona current waveform based on CNN

For the fitting of corona current waveform, it is necessary to construct different test environment to realize the fitting of corona positive and negative current waveform. Secondly, the waveform of government corona current is quite different, which is mainly reflected in local oscillation and superimposed interference. Therefore, in order to accurately describe the difference between positive and negative current waveforms, neural network model is needed to approximate the curve with arbitrary accuracy, and different network parameters are used to fit the current waveform. From the fitting results, it can be seen that the increase of the same number of neurons has an important value for improving the fitting speed and accuracy of current waveform.

4. Conclusion

In summary, the application of the tech and mathematical model represented by CNN in the mathematical model of corona current variation can realize the approximation of various precision to any function, and the CNN is helpful to realize the effective monitoring of corona discharge radiation signal. Based on the analysis of the fitting principle of the corona current mathematical model, this paper studies the learning mode of the BP neural network model of the corona current and the neural network model of the corona current. Based on the research of the curve fitting of corona current variation based on CNN, the arbitrary corona current waveform fitting and its results based on neural network mathematical model are analyzed.

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