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Optimization of Complex Systems Using Neural Networks: A Case Study on Power Systems

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Abstract: The optimization of complex systems is a critical challenge due to the numerous interacting factors and variables involved. Traditional optimization methods, such as gradient descent and genetic algorithms, often fall short in addressing these complexities. This study explores the application of artificial intelligence (AI) algorithms combined with neural networks (NN) for optimizing complex systems, specifically focusing on power systems. A fusion NN model is designed, incorporating feature extraction and data preprocessing methods tailored to the power system's characteristics. Experimental results demonstrate the model's high accuracy and applicability, meeting practical requirements for power system optimization. The findings suggest that this approach can be extended to other complex systems, such as transportation, logistics, and industrial control, enhancing AI's contribution across various fields.

Keywords: Neural Network; Artificial Intelligence Algorithm; Complex System; Electric Power System.

1. Introduction

In the 1940s, American psychologist McCulloch and mathematician Pitts put forward the M-PNN model, which started the theoretical research of NN model [1]. With the rapid development of science and technology, AI algorithm has been widely used in various fields [2]. As an important AI algorithm, fused NN has excellent nonlinear mapping ability and adaptive learning ability [3-4]. It provides strong support for solving problems in complex systems [5]. Therefore, the optimization of AI algorithm with NN in complex systems has important research significance and application value.

In complex systems, the optimization problem is of great significance [6]. Complex systems often involve many factors and variables, and the interaction between them is complex, which leads to the difficulty of optimization [7]. Traditional optimization methods such as gradient descent and genetic algorithm have some limitations in dealing with complex system optimization problems [8]. The AI algorithm with NN can learn and optimize adaptively, and can effectively deal with the problems of nonlinear mapping and uncertainty in complex systems, thus optimizing the performance of the system [9]. In this paper, aiming at the optimization problem in complex system, the optimization method of AI algorithm with NN is studied to improve the performance and stability of complex system.

2. NN Model

NN model is based on the basic principles of neuroscience and simulates the working mode of human brain neurons. Specifically, NN is composed of many interconnected neurons, and the output of each neuron depends on its input and activation function. Through training and learning, NN can adaptively adjust its internal parameters to realize the classification, prediction and generation of complex nonlinear patterns of input data. Compared with traditional optimization methods, NN model has some significant advantages [10-11]. Firstly, NN has adaptive learning ability, which can automatically extract features from data and automatically adjust model parameters according to the data, which makes NN more accurate and flexible in dealing with nonlinear problems in complex systems. Secondly, NN model can deal with large-scale and high-dimensional data, and can automatically process and organize information, which makes it have significant advantages in dealing with large-scale data in complex systems [12]. NN model is also widely used in complex system optimization. For example, NN can be used to predict the behavior and results of the system, optimize the configuration and parameters of the system, and control the development and evolution of the system. These applications can improve the performance and stability of complex systems and provide new ideas and methods for solving complex system optimization problems. However, there are some challenges and difficulties in the construction and application of NN model. For example, the training and learning of NN need a lot of data and time, and the training result may be influenced by many factors such as initial parameters, training methods and network structure. In addition, the training of NN may also fall into the problems of local minimum or over-fitting, which needs to be solved by adopting appropriate strategies.

3. Optimization of AI Algorithm based on NN

Optimization has always been one of the core issues in the field of AI, which involves finding an optimal solution to minimize or maximize an objective function. In complex systems, the optimization problem is usually more difficult, because there are many factors and variables in the system, and there may be complex interaction between them. Therefore, traditional optimization methods are often difficult to achieve ideal results. As a new optimization method, AI algorithm with NN can adaptively learn and optimize nonlinear mapping and uncertainty problems in complex systems by combining the advantages of NN and AI algorithm. Specifically, AI algorithm with NN can

automatically extract features from data, automatically adjust model parameters according to data, and can handle large-scale and high-dimensional data, and automatically process and organize information. These advantages make the AI algorithm with NN more accurate and flexible in dealing with complex system optimization problems.

The process of constructing a fused NN model suitable for complex systems can be divided into the following steps: (1) Determining the network structure: Firstly, the basic structure of NN needs to be determined. This can be determined according to the nature of the problem and the complexity of the system. For example, for a system with multiple inputs and outputs, an NN with a corresponding number of input layers and output layers can be used. At the same time, in order to improve the nonlinear mapping ability of the network, some hidden layers are usually added. (2) Select an appropriate activation function: Activation function is a vital part of NN, which determines the output of each node in the network. Common activation functions include Sigmoid, Tanh, ReLU, etc. They have different characteristics and can be selected according to the specific needs of the problem. In this paper, a nonlinear activation function is introduced into NN, and its formula is as follows:

$$f(x)=\begin{cases}1 & x \geq x_0 \\ ax+b & x_1 \leq x \leq x_0 \\ 0 & x \leq x_0\end{cases} \tag{1}$$

S-type transfer function is usually a monotone differentiable function with continuous values in (0,1) or (-1,1), which is often expressed by a kind of S-shaped curve such as logarithm or tangent, such as logarithmic S-curve:

$$f(x)=\frac{1}{1+e^{-x}} \tag{2}$$

S-type functions are smooth and asymptotic, and keep monotonic.

(3) Set appropriate parameters: The parameters of NN model include learning rate, momentum and regularization parameters, which have great influence on the training speed and performance of the model. Therefore, it is necessary to set appropriate parameters according to practical problems and experimental experience. (4) Determine the loss function: the loss function is used to measure the gap between the predicted results of the model and the actual results. For optimization problems, the loss function that can minimize the prediction error, such as mean square error, is usually selected. In this article, For a certain sample (WT, p), when the output y is not equal to the expected output p, there is an output error:

$$E=\frac{1}{2}(y-p)^2 \tag{3}$$

(5) Determine the optimization algorithm: the optimization algorithm is used to adjust the parameters of NN to minimize the loss function. Common optimization algorithms include gradient descent, stochastic gradient descent, Newton method and so on. According to the specific problems, we can choose the appropriate optimization algorithm. (6) Model building: All the above elements are combined together to build the final fused NN model. It should be noted that some adjustments may be needed in the construction process to make the model better adapt to the characteristics of complex systems. Generally speaking, when building the model, it is necessary to comprehensively consider various factors to get an efficient and accurate NN model. In order to avoid "saturation phenomenon", the input samples of NN are normalized in this paper. The normalization formula adopted is as follows:

$$X=\frac{I-I_{\min}}{I_{\max}-I_{\min}} \tag{4}$$

In the formula, X represents the normalized NN input value; I represents the unprocessed NN input value; $I_{\max}$ represents the maximum value of the NN input; $I_{\min}$ represents the minimum value of the NN input.

In order to further improve the performance and stability of AI algorithm with NN, some optimization strategies can be adopted. For example, multi-objective optimization algorithm can be used to consider multiple objective functions at the same time to obtain more comprehensive optimization results; Model selection and adjustment strategies can be used to select and adjust the structure and parameters of NN to improve the training effect and performance of the model. Multiple NN models can be integrated by ensemble learning to obtain better prediction results and generalization ability. In practical application, it is also necessary to consider the application scope and limitations of AI algorithm with NN. For some highly nonlinear and uncertain systems, it may be necessary to use more complex NN model or combine with other optimization methods to obtain better results. For some large-scale and high-dimensional data, data dimensionality reduction or feature selection may be needed to reduce the computational complexity and improve the performance of the model.

4. Results Analysis and Discussion

This holiday has an optimization problem of power system, which requires reasonable scheduling of power generation resources and loads to ensure the stability and economy of the system. The experiment will focus on the application of AI algorithm combining NN in solving power system optimization problems. The main goal of the experiment is to verify the effectiveness and superiority of the algorithm in reasonably dispatching power generation resources and loads and ensuring system stability and economy. This paper collects historical power data, including information of various power generation resources and various loads. At the same time, the influence of environmental factors and policy factors on power system and load will also be considered. Aiming at the optimization problem of power system, a depth NN model is designed. The model will automatically extract the characteristics of power system by learning historical data, and predict the future power demand and supply. At the same time, this paper uses genetic algorithm to optimize the parameters of NN to achieve more accurate power forecasting and more efficient power generation scheduling. The collected original power data are preprocessed, including data cleaning, format conversion, normalization and other steps, so as to facilitate the training and reasoning of NN model. At the same time, the NN model is trained by using historical power data, and the prediction error is reduced by constantly adjusting the parameters of the model. During the training process, the performance of the model will be monitored, and if it is found that the model cannot converge or the prediction

effect is not good, it will be adjusted.

Because there are many factors and variables in power system, and their interrelationships are complex, it is often difficult for traditional methods to achieve ideal results. The AI algorithm with NN can deal with the nonlinear mapping and uncertainty in complex systems adaptively, which provides an effective way to solve this problem. Figure 1 shows the error of the algorithm model.

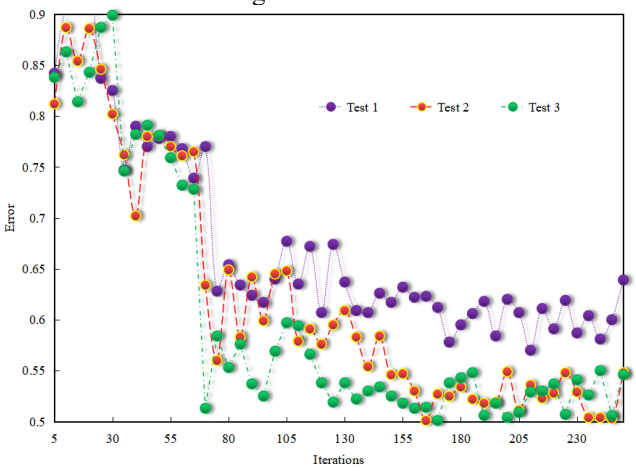

Figure 1. Error of algorithm model

From Figure 1, we can see that the algorithm proposed in this paper is excellent in error control. Specifically, the model error of the algorithm is low, which means that the algorithm has high accuracy and robustness when dealing with complex system optimization problems. This is because the fused NN model used in this paper has adaptive learning ability and can automatically adjust model parameters according to the characteristics of input data. This makes the algorithm better adapt to different complex system optimization problems, thus reducing the error. In addition, this algorithm uses appropriate data preprocessing and feature extraction methods, which makes the input data more in line with the input requirements of NN and improves the training effect and performance of the model. This also helps to reduce the error of the algorithm. Figure 2 shows the accuracy of the algorithm model.

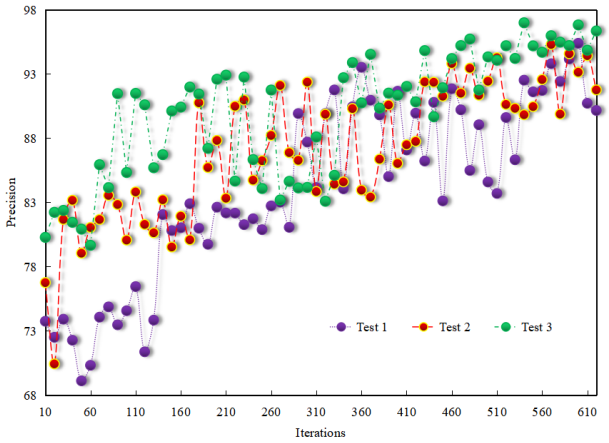

Figure 2. Accuracy of algorithm model

It can be seen from the results that the accuracy of this algorithm has reached a high level. Compared with traditional optimization methods, such as gradient descent method and genetic algorithm, the accuracy of this algorithm has been significantly improved. On the one hand, it benefits from the powerful nonlinear mapping ability of the fused NN model, which can better learn and simulate the complex dynamic behavior of the power system. On the other hand, it is also attributed to the multi-objective optimization strategy and model selection and adjustment strategy adopted in the algorithm, which makes the model perform better in dealing with practical complex system optimization problems. In addition, this algorithm also considers the economy and security of power system. In the process of model training, economy and safety are regarded as important optimization objectives, and multiple objective functions are considered comprehensively to obtain more comprehensive optimization results. This makes the algorithm in this paper have more practical significance and application value when dealing with the optimization problem of power system.

The experimental results in this section show that the algorithm in this paper has high accuracy and applicability in dealing with the optimization problem of power system, and can better meet the practical application requirements. This result proves the potential and practicability of AI algorithm with NN in dealing with complex system optimization problems. At the same time, this result provides strong support for further popularization and application of AI algorithm with NN.

5. Conclusion

In this paper, the application of AI algorithm combined with NN in complex system optimization is discussed, and it is verified by taking the optimization of power system as an example through experiments. Power system is a typical highly nonlinear, uncertain and time-varying complex system, and its operation state and performance are affected by many factors. At the same time, in the optimization of power system, because the demand and supply of power are constantly changing, a method that can predict and respond to these changes quickly and accurately is needed. Aiming at the characteristics of power system, this paper designs a fusion NN model suitable for power system. By introducing appropriate feature extraction methods and data preprocessing methods, the model can better adapt to the characteristics of power system and improve the training effect and performance of the model. The effectiveness and superiority of the model and algorithm are verified by experiments. The experimental results show that the algorithm in this paper has high accuracy and applicability in dealing with power system optimization problems, and can better meet the practical application requirements. The research in this paper can also be extended to the optimization problems of other complex systems. Similarly, AI algorithm with NN can be applied to solve optimization problems in transportation system, logistics system, industrial control system and other fields. By designing mixed NN models and optimization algorithms suitable for different fields, the application effect and contribution of AI in these fields can be further improved.

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