On-line Fault Diagnosis Technology and Application Based on Deep Learning of Fault Characteristic of Power Grid

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Abstract. In order to solve the problem of low accuracy of devices fault diagnosis in intelligent grid dispatching control system, this paper proposes a fault diagnosis method based on deep learning theory. First, building deep learning diagnosis models for various devices by extracting the characteristics of historical fault samples and training them. Then, when the dispatching control system of smart grid detects the risk and the online diagnosis function will integrate real-time fault signals for calling the diagnosis model. Finally, the probability value of this faulty device tripping will be obtained. In this paper, an online diagnosis system based on deep learning is built and its effectiveness in improving the accuracy of trip fault identification.

Keywords: Fault Characteristic, Diagnosis Model, Deep Learning, Power Grid

1. Introduction

The Supervisory Control and Data Acquisition (SCADA) systems in the dispatching control systems of smart power grids will send a large amount of fault signals to the dispatching centre when the power grid fails. Then the function of fault diagnosis, which has high requirements for the accuracy of signal and timing, will adopt expert rules [1, 2] to realize the online diagnosis by comprehensively utilizing data such as switch signals, general fault signals, protective signals, electrical measurement value, etc. With the further construction of the "Large-Scale Power Grid" operation system, the alarm information that reflecting the operation status of the power grid is centrally monitored by the dispatching centre, these all lead to new requirements for the perception of power grid operation situation, accurate analysis of massive fault signals and the ability of fault disposal. It is generally accompanied by numerous fragmented signals when accidents happen, and many of them are irrelevant signals. On the one hand, it may result in a high false alarm rate when setting loose diagnostic conditions to prevent missing reports; on the other hand, it may cause dispatchers unnecessary burden and is not conducive to the rapid insulation for faulty devices. Therefore, how to improve the efficiency of devices fault identification has become an important issue to be solved urgently.

The literature [3] summarized several intelligent methods that are widely used in power grid fault diagnosis field, including expert systems, neural networks, fuzzy set theory, Petri nets, etc., and
analyses the shortcomings of these methods based in a practical way. The literature [4] discusses a comprehensive fault diagnosis method based on multi-source information fusion to verify the correctness from original alarms and analysis results among multiple applications, aiming to optimize diagnosis results. However, lacking of self-learning ability and too heavy workload to establish and maintain expert knowledge database, may lead to a high risk of false alarm rate in the case of signal loss, timing disorder, and excessive interference signals. Literatures [5, 6] optimize the reasoning process and algorithm, then use the classic examples of the Petri net model to confirm. Still, this method has not been put into practical engineering application, so its practical level cannot be estimated.

With the improvement of technical theory and innovative practical work, artificial intelligence technology has penetrated into multiple application scenarios in the field of smart grids. Deep learning has been a research topic in the field of artificial intelligence, and many research results in fault diagnosis based on deep learning technology have emerged. Literatures [7]-[9] point out that deep learning is often applied to data analysis for prediction, fitting or classification. They also discuss how to use artificial intelligence technology to achieve smart grid upgrades, and analysis the development stage and application research of artificial intelligence under the background of big data in depth. The literatures [10-12] propose the overall application framework of artificial intelligence in the field of dispatch, which is focusing on artificial intelligence and existing grid regulation technology. Meanwhile, these studies have been dedicated to many typical scheduling application scenarios, such as investigate fault identification, load forecast, intelligent assistant decision and voice interaction.

In this paper, an online fault diagnosis method for power grid devices based on deep learning is proposed in order to eliminate the defects of current fault diagnosis. Through mining data characteristics of real fault, a fault diagnosis model based on deep learning is constructed. When a fault occurs, the fault characteristic vector in the current state is loaded into the diagnosis model to realize the fault diagnosis. It has been verified that this method has higher accuracy and better fault tolerance than the diagnosis method based on the expert knowledge database. It will provide an intelligent basis for dispatchers to identify fault rabidly and improve their capability of intelligent fault disposing.

2. Overall framework
The on-line fault diagnosis method of power grid devices based on deep learning is mainly divided into three parts: fault characteristic extraction, diagnosis model construction. The architecture of the method is shown in figure 1.

![Figure 1. Architecture diagram of online fault diagnosis method for power grid devices based on deep learning.](image-url)
3. Fault characteristic extraction

The fault characteristic extraction function integrates the related data to form regular characteristic samples.

3.1. Characteristic information pre-processing

After the grid failure, protection devices will produce a large number of signals, and the circuit breakers’ statuses and electrical measurement values may also change frequently [1]. The smart grid dispatching control system stores the relevant signals in the database, which provides sufficient training samples for deep learning.

AC line, bus, transformer and generator are the most concerned types of power grid faults. Firstly, the sample format is designed according to characterize the fault characteristics of different devices. Taking AC line fault as an example, AC line fault is often accompanied by signal and power flow changes such as total accident, protection action, reclosing, switch displacement, etc. According to the characteristics of these signals, the characteristics of AC line faults can be summarized in Table 1.

Table 1. Characteristics and description of AC line fault.

| Fault Characteristic       | Description                                                                 |
|----------------------------|------------------------------------------------------------------------------|
| total accident             | There is total accident signal or interval total accident signal in the station at the beginning/end of the line. |
| protection action          | There is line protection action, line topology connection switch protection action. |
| reclosing                  | There is line reclosing action.                                               |
| switch displacement        | The line topology is connected and the switch is changed.                     |
| Power flow                 | There is a sudden change in line power flow.                                  |

The fault characteristic extraction function extracts relevant fault information from the database, processes each characteristic parameter with digital rules, and finally expresses it as a concise and clear learning sample in the form of vector. For example, if there are general fault signals in this alarm, the characteristic bit of general fault signal is recorded as 1, otherwise it is recorded as -1; if the line connected switch 1 is closed at the beginning of sampling, the characteristic bit is recorded as 1, and the opening is recorded as -1. After regularized processing, the fault information will eventually form a fault characteristic sample which is only composed of 1 and -1, so that the computer can carry out build an intelligent fault diagnosis model through deep learning.

3.2. Sample label

The dispatching control system of smart grid stores a large number of historical alarm information, including real and false alarm fault. After the fault, the dispatcher manually verifies and confirms whether it is a real fault. Fault diagnosis is an independent classification problem, and the optimal diagnosis model should be obtained by supervised learning under the premise of knowing the real fault. Supervised learning is equivalent to random pattern learning with prior knowledge. Compared with unsupervised learning without labels, directional analysis and modelling of sample data under label constraints can play a greater learning value of sample data, and the accuracy of the model can be higher.

For the regularized fault characteristic samples, the trip records made by the dispatcher can be used to encode the samples with one hot code, that is, one-bit effective code. When the sample is a real fault, the label is set to 1, otherwise it is set to 0. Finally, the vector with label bit is formed this vector can directly participate in the training of diagnosis model.
3.3. Sample expansion
Deep learning is a machine learning method which depends on large data sets. Too small sample data sets can easily lead to over fitting or insufficient generalization ability. However, under the background of the current strong smart grid growing, the sample size of real fault caused by fault trip usually cannot meet the requirements of deep learning, so the concept of sample expansion needs to be introduced.

For the same type of devices, the differences of their performances and working environment have little influence in the case of fault. It can be considered that the same type of devices has the same characteristics, that is, when a trip fault occurs, it will usually trigger similar signals. It can be inferred that for the extracted characteristic samples of the same type of devices, there must be a strong correlation between the eigenvalues of the corresponding characteristic bits.

The idea of sample expansion is as follows: firstly, probability statistics is used to extract the overall characteristics of the sample, that is, to calculate the conditional probability of each signal occurrence (i.e. the eigenvalue is 1) in the statistical characteristic sample under a certain condition (the training sample is real fault sample or non-fault sample); then random sampling method is used to simulate the sample, that is, assuming the probability of the general signal in head station caused by AC line fault is \( p \), a random number is \( r(0<r<1) \), it is considered that there is general signal in the simulation sample if \( r<p \), and the characteristic value of this bit is 1. Each eigenvalue is supplemented by random sampling in turns. The label bit directly generates the same type as the sample to be simulated. The label and all eigenvalues are spliced to form a completed simulation sample. If this method is repeated, enough samples can be expanded.

4. Diagnosis model construction and self-learning
The regular samples construct the diagnosis model and constantly update and optimize to get the fault diagnosis model.

4.1. Deep learning model
Deep learning is the deep development of neural network, through building a multi-layer structure similar to neural network and using massive data for training. According to the different application environment, convolution neural network (CNN), recurrent neural network (RNN) and fully connected neural network (FNN) are widely used in supervised deep learning model. Among them, convolutional neural network focuses on the relationship between local area characteristics and other adjacent local area characteristics, and is widely used in graphics classification, scene recognition and other fields; cyclic neural network is determined by the current output and previous information of a sequence, and is suitable for speech recognition, natural language processing and other scenes; fully connected neural network is a classical feedforward neural network with simple unit structure and any nonlinear function can be fitted theoretically by adjusting the neuron activation function, the number of hidden layers and the weight. Thus, fully connected neural network is selected as the network model structure of deep learning in this paper.

Fully connected neural network is composed of input layer, multi hidden layer and output layer, which is similar to the structure of human brain. Only nodes in adjacent layers are connected: any neuron in the upper layer is connected with all neurons in the lower layer, and nodes in the same layer and cross layer are not connected with each other. Fault devices diagnosis based on deep learning is a multivariate analysis method to study the relationship between sample characteristics and fault probability. Logistic regression model can be used for continuous numerical prediction to improve the accuracy of the model.

The training process of neural network is essentially an optimization process to update parameters and minimize the error. RMSProp optimizer can be used to adjust the weight to minimize the loss function value.
4.2. Self-learning of diagnosis model
When it is used for the first time, the historical fault samples are used as the training set for offline training of the diagnosis model. After the system runs stably and new faults occur, the labelled samples can be exported from the database regularly for dynamic updating iteration of the model. With the increase of service time, the number of real fault samples in learning samples is increasing, and the accuracy of fault diagnosis model will be greatly improved.

5. Online intelligent diagnosis
The online intelligent diagnosis function is based on the research of fault characteristic extraction and diagnosis model training. When the dispatching control system senses the alarm sent out by power grid, the online intelligent diagnosis function will automatically integrate the fault related signals according to the type of alarm devices, extract the fault characteristics to form the characteristic vector, call the corresponding diagnosis model, and finally get the probability value of the real fault of the devices. The probability value and fault characteristics will be saved to the database for easy reference.

The online intelligent fault diagnosis process based on deep learning is as follows.
(1) Collecting historical fault samples, extracting sample characteristics according to devices types, setting sample labels according to trip records, and forming characteristic vectors after digital rule processing;
(2) Expanding real and non-real fault samples respectively to obtain sufficient training samples;
(3) Setting the training model parameters of fully connected logistic regression neural network, including the number of layers, activation function, optimizer, etc;
(4) Using training sample set to train the diagnostic model, and adjusting the training parameters to make the output loss and accuracy meet the requirements. Finally, the corresponding fault diagnosis model is obtained;
(5) The new fault alarm triggers online intelligent diagnosis function of dispatching control system, extracts the eigenvalues of real-time fault samples and processes the digital rules to form the characteristic vectors to be diagnosed;
(6) Loading the characteristic vector to be diagnosed into the corresponding diagnosis model according to the type of alarm devices. After the diagnosis, the probability value of the real fault and fault characteristics are returned and saved to the database. At the same time, the information will be pushed to the workstation;
(7) Exporting the historical fault samples from the database regularly, and updating the diagnosis model according to steps (1) to (4).

Using this online intelligent diagnosis method does not need to replace the original diagnosis function of the dispatching system, which provides an intelligent basis for the dispatcher to quickly identify the fault. It can effectively reduce the fault false alarm rate and improve the dispatcher's intelligent fault handling ability.

6. Example analysis
The online intelligent diagnosis system is based on D5000 platform of smart grid dispatching control system. The fault feature extraction function is deployed in safety zone I, and the training of fault diagnosis model is deployed in safety zone III. The model training function is written and developed in Python. This paper collects the alarm information and trip records of an area from 2018 to 2019. Taking AC line fault alarm as an example, the fault samples processed by digital rules include 16 bits eigenvalue and 1 bit tag. After sample expansion, a total of 4000 fault samples are obtained and arranged randomly. The last 30% of the samples are used as test sets for model verification. Through experimental comparison and analysis, ReLU function is the best choice for the activation function of the hidden layer neurons in the training model, sigmoid function is used for the activation function of the output layer, and RMSPROP method is selected for parameter optimization. After the model training, fault diagnosis models of AC line, bus, main transformer and generator are obtained respectively.
All the alarm information from January to April in 2020 is loaded into the diagnosis model as a test set. Compared with the trip records, the accuracy of real fault prediction is higher than 90%. The diagnosis results are integrated into the integrated intelligent alarm visual interface of the intelligent dispatching system for display, so that the dispatcher can understand the probability and fault characteristics of the alarm as a real trip fault.

7. Conclusion
Aiming at the problem of high false alarm rate in existing intelligent dispatching system, this paper proposes an online fault diagnosis method for power grid equipment based on deep learning. Firstly, the historical fault samples of all kinds of equipment are integrated to extract the fault eigenvalues and labels to form the training sample set; secondly, the training model is constructed based on Keras library, and the model is optimized to the allowable error range by adjusting the iteration times, the number of samples obtained in each training and other parameters; the new alarms of power grid are monitored in real time, the relevant alarm signals are integrated, the eigenvalues are extracted and the model is called. In order to improve the accuracy of the diagnosis model, the training samples are updated regularly to realize the self-learning of the diagnosis model. Through the actual data test, the application of this method for fault diagnosis can effectively reduce the false alarm rate, and provide a strong guarantee for the dispatcher to carry out the fault disposal work in time and improve the intelligent level and efficiency of power grid monitoring operation.

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