Single-phase ground fault identification method for distribution network based on inception model and sample expansion

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Abstract. A single-phase ground fault identification method based on inception model and sample expansion was proposed in this paper. Based on the basic characteristics of the inception model, a hybrid inception model structure is constructed to enhance the width and depth of the network and reduce network parameters. Combined with the training sample expansion method, the model is fully trained to adapt to the single-phase ground-fault current characteristics of the distribution network. The experimental results show that the accuracy for the hybrid inception model structure to the single-phase ground-fault current of the distribution network is 94.21%. After the sample is expanded, the recognition accuracy rate can be further improved by 97.52%.

1. Introduction
The distribution network is the last mile for the transmission of electrical energy from the producers to the users. It is an important public infrastructure that promotes the development of the national economy and social progress, and an important foundation for the advancement of science and technology. The rapid and accurate identification of single-phase grounding fault types in distribution network is helpful to timely treatment of fault and improves the reliability of power supply[1,2].

At present, the identification of single-phase ground fault in distribution network is based on the extraction and comparison of fault phase characteristics. If the extracted single-phase ground fault characteristics are directly compared and judged, it will be affected by other interference sources in the distribution network, and the accuracy is low. Intelligent algorithms can avoid the influence of interference sources in the distribution network. However, due to the particularity of grid data, it is generally difficult to obtain enough sample data to fully train intelligent algorithms. The choice of algorithm is also directly related to the effect of fault identification, and its applicable range is limited by the training samples provided[3-5].
This paper proposes a single-phase ground fault identification method for distribution network based on inception model and sample expansion. In view of the characteristics of single-phase grounding fault in distribution network, the multi-layer convolution operation and pooling operation of current waveform are carried out by using hybrid concept model structure. Different sizes of image representation are obtained to accurately grasp and identify the fault phase. The sample expansion method is used to expand the training samples based on the actual samples and the characteristics of the distribution network. It can meet the requirement of sufficient training samples and improve the adaptability and accuracy of the recognition method.

2. The identification process of single-phase grounding fault in distribution network
The overall process of single-phase grounding fault identification in distribution network is shown in figure 1, which mainly includes the following steps.

1) Data preprocessing. Collect the synchronous current recording data recalled on the three-phase fault indicator after a fault occurs. The data are standardized preprocessed and placed in different folders according to the order of distribution network topology.

2) Fault line selection and location. Fault line selection is based on the recorded data of the same set of fault indicators. Fault location is based on the recorded data of all fault indicators on a phase line after line selection.

3) Fault identification and judgment. Based on the fault location, the current waveform image is filtered out. The fault types are identified and determined by using the concept model.

4) Manual verification of faults. The fault location and the fault type are provided to the staff. Handle the fault on site, and check the type and location of the fault.

5) The establishment of fault sample database. According to the fault data, fault location, fault type and check information, a fault sample library is established.

6) Expansion of training samples. The method of transformation and fault simulation is used to expand the sample size to meet the requirement of sufficient training samples in step 3.

It is not difficult to find from the specific steps of the single-phase ground fault identification process in the distribution network. The key to determining the fault identification is the identification model and the number of samples.

Figure 1. Overall flow chart of single-phase grounding fault identification in distribution network.
3. Hybrid inception model
In order to adapt to the characteristics that the waveform characteristics of single-phase ground fault current in distribution network are not obvious, the hybrid concept model structure is designed, as shown in figure 2. By modifying the input and output size of network layer and adjusting the structure of filter, each Inception structure can extract different scale feature maps on the corresponding convolution layer features. Extracting features of different scales on the same current waveform can improve the recognition accuracy. The core part of this hybrid inception model structure is: 1) using small convolution kernel to replace large convolution kernel, such as using 3 × 3 and 5 × 5 convolution to replace 7 × 7 convolution to reduce parameters; 2) using normalization layer to avoid the loss of gradient and improve the speed of learning convergence.

![Figure 2. Multi-inception structure suitable for single-phase ground fault identification of distribution network.](image)

4. Sample expansion method
Single-phase ground faults account for about 70% of distribution network faults, but the number of fault waveforms collected is not large. The fault waveform that can be obtained is far less than the number of samples needed for the training of the inception model. In order to meet the training requirements of the algorithm, the sample size must be expanded.

4.1. Gaussian deflection of fault waveform
The fault waveforms collected by different fault indicators are different in sampling points, period and harmonic interference. The fault waveform samples are processed by Gaussian deflection to simulate the collection of the same ground fault waveform by different fault indicators to achieve the purpose of sample expansion and eliminate the impact of the fault indicators on fault identification. Figure 3 shows the image of single-phase grounding fault waveform before and after Gaussian deflection processing. The outer contour of the fault waveform is almost unchanged, but there are some differences in the current sudden change time, amplitude and duration.
4.2. Fault waveform simulation

The majority of single-phase ground faults in distribution networks are due to surrounding environmental factors. With time, the environment around the line is also changing. The evolution of environment will lead to new single-phase ground faults (new location, new factors, etc.). The training samples for intelligent algorithms do not contain these types of faults. After training, the intelligent algorithm is prone to misjudgment in the initial identification of this kind of fault. Therefore, it is necessary to expand the capacity of such failures in the training samples.

According to the real line parameters of a regional distribution network, the simulation model is established, and the current waveform of simulated single-phase grounding fault is shown in figure 4. The simulated fault current waveform and the waveform recorded by the fault indicator are completely consistent in the change trend. Because the simulation model is lumped parameter and the actual line is distributed parameter, there is a certain error in numerical value. The similarity between the simulated waveform and the actual recorded waveform and the acceptable error range verify the feasibility of using simulation to simulate the single-phase ground fault of the distribution network. This method can accurately and quickly simulate various types of single-phase grounding fault in distribution network, expand the number of samples, meet the training requirements of the intelligent algorithm, and improve its adaptability.
5. Experimental results and analysis

5.1. Samples
The actual sample used in this article is the fault data of a province's distribution network in 2019, and the specific type distribution is shown in Table 1. 90% of the training samples were randomly selected as training samples. The remaining 121 pictures were used as test samples. 800 current waveforms in training samples are processed by Gaussian deflection of fault waveform, and 1600 expansion samples are obtained. 50 regional distribution network lines are established, and 572 single-phase grounding fault waveforms are simulated. After the expansion, the number of training samples is 3258, which is three times the number before expansion.

| Fault type                     | Number of samples | Proportion of samples (%) |
|--------------------------------|-------------------|---------------------------|
| Arrester fault                 | 102               | 8.45                      |
| Transformer fault              | 46                | 3.81                      |
| Cable body fault               | 187               | 15.49                     |
| Cable accessory fault          | 34                | 2.82                      |
| Cable damaged by external force| 68                | 5.63                      |
| Disconnection                  | 187               | 15.49                     |
| Crossbar                       | 51                | 4.23                      |
| Insulator fault                | 51                | 4.23                      |
| Switchgear equipment           | 153               | 12.68                     |
| Foreign objects on the line    | 272               | 22.54                     |
| User incoming cable fault      | 68                | 5.63                      |

5.2. Experiment process
In order to verify the performance of the hybrid concept model structure, two groups of experiments were carried out and compared. One group used 1086 training samples before expansion, the other group used 3258 training samples after expansion. Model training was carried out respectively.

5.3. Experiment results and analysis
The change of model recognition accuracy is shown in figure 5. As the number of iterations increases, the recognition accuracy is increasing. The rate of ascent rises first, then slowly, and finally stabilizes. After the expansion, the number of samples increases, and the training is more sufficient. The model parameters are adjusted more accurately, so it needs more iterations to achieve stability. it is about 3000 times. The model training before the expansion of the sample was stable after 1500 times.

![Figure 5. Training results of mixed perception structure.](image-url)
After 5000 iterations of training, 121 randomly selected test samples were used for testing. The test results are shown in Table 2. The recognition accuracy of the proposed hybrid inception model is 94.21% before the expansion of training samples, which achieves the expected goal. When the sample is expanded, the recognition accuracy is further improved to 97.52%, which verifies the effect of sample expansion on improving the recognition accuracy.

Table 2. Experimental verification results.

|                        | Number of training samples | Number of test samples | Number of misjudgments | Recognition accuracy |
|------------------------|---------------------------|------------------------|------------------------|----------------------|
| Before sample expansion| 1086                      | 121                    | 7                      | 94.21%               |
| After sample expansion  | 3258                      | 121                    | 3                      | 97.52%               |

6. Conclusion
This paper proposes a single-phase ground fault identification method based on the inception model and sample expansion. The hybrid inception model structure is used to enhance the depth, width adaptability of the network. The parameters of the network are reduced, and achieve the purpose of multi-scale feature extraction. Combined with the training sample expansion method, the model can meet the requirements of full training, and further improve the accuracy of single-phase ground fault current identification of distribution network.

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References
[1] Tong, X., Zhang, S. (2019) Grey Relational Degree Based Fault Section Location and Type Recognition Method for Distribution Network. Automation of Electric Power Systems. 43: 113-118.
[2] Lu, J., Mu, L. (2012) A practical identification for single-phase ground fault of microgrid. Power System Protection and Control. 40: 11-15.
[3] Yang, S., Dai, C., Li, F., et al. (2020) Fast short-circuit fault identification method based on phase current difference. Power System Technology. 44: 1-6.
[4] Zhang, J., Yang, F., Guo, M. (2018) High impedance ground fault detection based on time-frequency characteristics and SVM. Electrical engineering. 19: 37-43.
[5] Weng, Y., Chen, X., Xiao, X., et al. (2020) High impedance ground fault PSO and identification technology based on Bayes classifier. Electrical Measurement & Instrumentation. 57: 52-56.