Research on Zero-Sequence Insulator Detection Technology Based on Deep Learning

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Abstract. With the expansion of power grid scale, the method of manual inspection is more and more difficult to implement. Nowadays, it is possible to use infrared imaging equipment and target detection method based on deep learning technology to intelligently detect zero-sequence insulator. In this paper, zero-sequence insulator detection technology based on in-depth learning is proposed to detect zero-sequence insulators with different contamination, air humidity and different locations. This technology has the characteristics of low investment cost, high accuracy and strong adaptability in complex environment, which can reduce the labor intensity and workload of power grid patrol personnel. The high accuracy of the system can effectively reduce the outage accidents caused by the deterioration of insulators in the power grid, thus ensuring the safe and stable operation of the power grid.

1. Introduction

Insulator is an important component of power equipment, which plays an important role in connecting conductors and towers. Insulators with good performance can ensure the stable operation of power system. Insulators have been exposed to various complex natural environments for a long time. Their performances are not only affected by external environment, but also by electromagnetic field and stress. They eventually become zero-sequence insulators[1]. Zero-sequence insulators in harsh environments will cause string breakage, wire drop and other accidents, and even lead to serious regional power outages[2]. Zero-sequence insulator has seriously endangered the development of national economy and people's daily life. Therefore, eliminating deterioration and zero-value insulators in power grid equipment in time to ensure the stability and safety of power grid has become an important issue.

With the expansion of power grid scale, the method of manual inspection is more and more difficult to implement. Nowadays, it is possible to use infrared imaging equipment and target detection method based on deep learning technology to intelligently detect Zero-sequence insulator[3]. This technology has the characteristics of low investment cost, high accuracy and strong adaptability in complex environment, which can reduce the labor intensity and workload of power grid patrol personnel. The high accuracy of the system can effectively reduce the outage accidents caused by the deterioration of insulators in the power grid, thus ensuring the safe and stable operation of the power grid.
2. Principle Introduction
Firstly, the position of insulator string in infrared image is located by depth learning method, and then the insulator string is judged as Zero-sequence insulator by analyzing the thermal characteristics of insulator string in infrared image. The flow chart is shown in Fig.1. Next, we mainly introduce the heating principle of Zero-sequence insulator, the imaging principle of thermal infrared image and the related research results of target detection technology based on depth learning.

![Flowchart of algorithm](image)

2.1 Thermal characteristics of zero-sequence Insulator
There are three sources of heat for insulators in operation. The first is that insulators are contaminated on the surface of atmospheric environment, and the heat generated by leakage current is transmitted through contamination[2]. The second is the heat generated by penetrating current conduction inside insulators, which is caused by tiny holes generated by the manufacturing process of insulators themselves. The third is the dielectric heating of insulators. Under the action of electric field generated by strong current, the movement of dielectric molecules produces a lot of loss heating.

The results show that the resistance of deteriorated insulators decreases, which leads to the increase of internal penetrating current, that is, the second kind of calorific value increases, and the temperature of insulators increases. When the resistance of the insulator is reduced to the equivalent capacitive reactance, the calorific value of the deteriorated insulator will reach the peak, and the difference between the deteriorated insulator and the normal insulator is most obvious in the infrared image. When the deteriorated insulator loses its insulation performance and becomes a zero value insulator, there is no medium heating because the voltage at both ends of the zero value insulator is zero. At the same time, because the resistance of the zero insulator is very small, the leakage current does not generate heat basically, and ultimately the temperature of the zero insulator does not rise basically. At this time, the relative temperature difference between the insulator and the adjacent normal insulator is the largest, which is also an important basis for us to distinguish the deterioration of the insulator by thermal infrared image.
2.2 Infrared image
The infrared thermal imager receives the thermal infrared radiation energy of the object through the photosensitive element in the sensor, converts it into the current intensity signal, and finally quantifies it into the infrared thermal image of gray value[4]. So, like optical cameras, the gray value of a pixel in a thermal infrared image reflects the real-time temperature of that point in space. The higher the temperature of the target point is, the greater the current intensity is, the bigger the gray value of the corresponding infrared image is, and the brighter the target point is reflected in the infrared image[5]. When insulators are in collusion with electricity, insulators are heated to distinguish them from their surroundings. When part of the insulator string deteriorates to zero value insulator, because the resistance is zero and does not heat, the temperature difference between the region and the environment is not large, but compared with the adjacent insulators, the temperature difference is very large. As can be seen from Figure 2, the normal insulator is brighter than the background color in the infrared image, and the central part has the largest calorific value due to the conduction current; while the zero-value insulator has a part of gray value close to the background color, indicating that this part has deteriorated and lost the insulation ability.

![Figure 2. Normal and Zero Insulators](image)

2.3 Deep Learning
Deep learning is a new research field of machine learning in recent years. Its basic idea is to simulate the connections between human brain neurons. Through in-depth learning, we can deal with some complex perception problems. As deep learning has made breakthroughs in speech recognition, computer vision and other applications, this technology has been widely used in various fields of industrial production. Among them, convolutional neural network (CNN) is a deep learning model for two-dimensional image data. By introducing local receptive field and value sharing mechanism, the recognition effect of generalization ability of image recognition is greatly improved. Convolutional neural network directly takes the input image processing object and output as the target detection result and its probability. Because of the influence of weight sharing mechanism, convolutional neural network has a good adaptability to image translation, rotation and scaling. Compared with the traditional image algorithm based on artificial features, the convolutional neural network completely abandons the complicated process of feature design and extraction. In this paper, zero-sequence insulator recognition model based on convolution neural network is constructed.

3. Heating test of insulator
In order to understand the heating characteristics of insulator strings, especially zero-sequence insulator. Firstly, we simulate the heating experiment of insulator strings at different locations, humidities and contamination levels in laboratory environment to obtain the heating image data of zero-sequence insulators and construct the thermal infrared image database.
3.1 Laboratory Equipment

According to GB/T4585-2004/IEC60507:1991-"Artificial Pollution Test of High Voltage Insulators for AC Systems", the test principle is shown in Figure 3. Voltage regulator is coil-shifting regulator, rated input voltage 220V, output voltage 0-250V, rated capacity 15KVA. The actual voltage regulator is shown in Fig. 4. The protective resistance value is 10KΩ. The power supply is provided by 10KVA/100KV power frequency test AC transformer. The high voltage side conductor is introduced into the artificial fog chamber through epoxy bushing. The sample was suspended in an artificial fog chamber of 2000 mm × 1300 mm × 1300 mm. The steam was generated by an ultrasonic atomizer, and the humidity in the device was changed. The temperature and humidity in the fog chamber were monitored by a thermohygrometer. Fixed the sample on the test platform and applied voltage at both ends of the insulator string. When pressurizing, the test voltage is rapidly boosted by uniform boosting, and then continuously pressurized by constant voltage for 1 hour. The voltage is monitored by a capacitive voltage divider with a partial voltage ratio of 3000:1. At the same time, the temperature distribution of insulator strings was taken by infrared thermal imager. Infrared thermal imager: FLIR T440, measuring range -20℃ ~1200℃, thermal sensitivity < 0.04℃, 320×240 pixels, spatial resolution 1.36 mrad, measuring accuracy (±2℃) or reading (±2%) and has continuous zoom function.

3.2 Experimental steps

(1) In the case of no power supply, the stained and shady insulators are connected in series and suspended in the artificial fog chamber. The insulator cap at the low-voltage end is connected with the grounding wire to make it reliably grounded. The insulator iron foot at the high-voltage end is
connected with the high-voltage line, and the artificial fog chamber is closed after the wiring is completed.

(2) Turn on the power supply to pressurize. When pressurizing, the test voltage is boosted up by uniform and fast boosting method. Then the constant voltage method is used to continuously pressurize, and the capacitive voltage divider is used to monitor the voltage.

(3) Opening the humidification system makes the air humidity in the artificial fog chamber increase gradually until the target humidity value is needed for the test. Temperature and humidity sensors are used to monitor the temperature and humidity in the artificial fog chamber.

(4) Turn off the power supply after half an hour of continuous pressurization, record the ambient temperature and humidity, and collect the infrared thermal image of insulator string with high-precision infrared thermal imager. Then the insulator string is stationary and tested by infrared thermal imager until the residual heat of insulator is eliminated, so as to avoid affecting the subsequent test.

(5) Repeat (1) - (4) steps after changing the position of zero insulator (high voltage end, middle position, low voltage ground end).

(6) After changing the target humidity (60%, 70%, 80%), repeat the above steps (1) - (5).

(7) After replacing insulators with different contamination (0.03mg/cm2, 0.05mg/cm2, 0.1mg/cm2 and 0.2mg/cm2), repeat the above steps (1)-(6).

3.3 Experimental results

1) Heating characteristics of zero-sequence insulators at different locations

In order to understand the influence of the location of the zero-sequence insulator on the temperature distribution of the whole insulator string when there are zero-sequence insulators in the contaminated insulator string, relevant experiments were carried out. The positions of insulators in contaminated insulator strings are numbered from high voltage terminal to low voltage grounding terminal. zero-sequence insulators are selected to be placed in high voltage, middle and low voltage grounding positions during the test, and infrared detection of insulator strings is carried out respectively.

Combining with Figure 5, it can be seen that when the zero value insulator is at the high voltage end (No. 1), the middle position (No. 2) and the low voltage ground end (No. 3) of the insulator string, the zero-sequence insulator has the same thermal characteristics, that is, the temperature of the zero-sequence insulator is lower than that of the normal insulator. This is mainly due to the fact that under the same current, the resistance of the zero insulator is almost zero, the voltage at both ends is almost zero, the heating is not obvious, the image of the normal insulator is dim, and the resistance of the normal insulator is large, the voltage of the normal insulator is large, and the image heating is brighter than that of the zero-sequence insulator.

2) Heating characteristics of zero-sequence insulator with different moisture

In order to analyze the influence of environmental relative humidity on the temperature distribution of contaminated insulator strings with zero-sequence, relevant experiments were carried out.

Combining with Figure 6, it can be seen that when the relative humidity is low, the insulator surface is polluted and dry, and the salt-attached conductive layer on the polluted insulator surface presents a larger resistance. Although the leakage current on the insulator surface will increase, the thermal effect will also increase. However, the
temperature rise of normal insulators is still small, which is close to the zero surface temperature, and is still not conducive to infrared detection of zero insulators.

3) Heating characteristics of zero-sequence insulators with different pollution degrees

In order to analyze the influence of surface contamination of insulators on temperature distribution of contaminated insulator strings with zero value, relevant experiments were carried out. Figure 7 shows the test results of surface temperature distribution on insulator strings with different contamination under the same relative humidity condition (80%) and zero value insulators.

![Figure 7. Infrared image of insulator string with different contamination](image)

4. Thermal Infrared Image Processing

A large number of infrared image images of insulator strings were taken in laboratory environment and real environment. Firstly, the infrared image was denoised, and then the contrast of background and target was increased by image enhancement. Finally, the infrared image is used to establish the sample database.

4.1 Image Denoising

Different from the visible light sensor, the infrared camera perceives the thermal radiation intensity of objects, so the contrast of infrared images is not high. The gray value of most targets and background gray value are close, and infrared images are very sensitive to noise. Noise points are common in infrared images[6]. In order to filter out the noise data in infrared image and improve the contrast and clarity of infrared image, we use adaptive filter to process infrared image. The characteristic of the adaptive filter is that it can automatically adjust the filter coefficients, and it has better filtering effect for image random noise. At the same time, since the adaptive median filter is not processed by Gaussian smoothing, this method can ensure that the edges of key targets are not lost, the overall contrast of the image is not reduced, and the random noise of the image is removed at the same time.

4.2 Image Enhancement

As shown in Figure 2, there is little difference between the edge gray value of insulator string and the background gray value in infrared image. The purpose of image enhancement is to enhance the contrast of this part so that the insulator part and the target background part can be distinguished. Therefore, in practice, the algorithm needs to automatically calculate the upper and lower thresholds of the filter, where the lower threshold is the value to distinguish the dark part of the target from the background, and the upper threshold is the value to distinguish the dark part of the target from the bright part of the target. After two thresholds are obtained, the gray value of the infrared image is linearly raised, and the overall contrast of the infrared image is enhanced.

4.3 Establishment of sample database

After thermal infrared image preprocessing, we need to establish our own sample database. Because the effect of the network model depends directly on the abundance of the sample database. When the annotation result of sample database is accurate and the type is rich, the network model can have better generalization ability.

5. Deep Learning to Target Detection

Faster RCNN is a classical target detection algorithm in the field of target detection[7]. Faster RCNN consists of two CNN networks: Regional Proposal Network (RPN) and Fast RCNN Detection Network[8]. The core idea of RPN is to generate region proposal directly through convolution neural network. RPN and Fast-RCNN share the convolution layer. In the feature map of the last shared
convolution layer, sliding small windows are connected to the space window of n*n. Figure 8 is a flow chart of Faster-RCNN.

![Flow chart of Faster RCNN](image)

Figure 8. Flow chart of Faster RCNN

Taking the infrared image insulator sample database as training sample, the training and application of Faster RCNN model mainly includes the following key steps:

Step1: Pre-training CNN model RPN network and Fast RCNN network need original convolution neural network to extract features. Therefore, the initial parameters of the network are obtained by initializing the network through the ImageNet classification library. According to the complexity of the network, it can be divided into VGG network and ZF network. In this paper, only one kind of insulator is collected, and the data scale is relatively small, so only ZF network is enough. The first five layers of ZF network are convolution layer and the last three layers are full connection layer. After ZF model calculation, RPN and Fast RCNN are obtained by adding specific layers.

Step2: RPN network training initializes the common convolution neural network through Imgnet, which makes the coiler network before RPN have the basic image feature recognition ability. On this basis, using the network to continue training insulators as a specific goal, the RPN network parameters are fine adjusted. In the shared convolution layer of CNN network, 256 feature maps as input of RPN network and Fast RCNN network are obtained. RPN network uses 3*3 convolution kernel (sliding window) to convolute the feature map provided by shared convolution layer, and obtains a 256-dimensional feature vector representing the corresponding position of the original image.

Step3: The joint training of RPN network and Fast RCNN network is carried out in Faster RCNN. The output of shared network layer is used in RPN network and Fast RCNN network respectively. The joint training of these two networks can make the parameters of shared network layer more reasonable and facilitate the training and identification of target objects. The specific training method is to alternately optimize learning to share features. First, the RPN network is pre-trained through the Imagenet library, and secondly, the RPN is trained by the end-to-end fine-tuning using Step2 to get regional recommendations. The end-to-end fine-tuning training of Fast RCNN is carried out with the purpose of detection by using regional recommendations. Then, through the trained Fast RCNN, the RPN network is re-initialized and the shared convolution layer is fixed. Finally, fine-tune the layer specific to Fast RCNN.

Step4: Take any size image as input of the shared convolution network layer and extract the shared feature map. The region recommendation network RPN generates target candidate boxes, retaining the top 300 boxes with higher scores. Through Fast RCNN network, 300 frame corresponding characteristic diagrams are calculated, and the test results of insulators are obtained. The test results are shown in Figure 9.
6. Summary and Prospect
In this paper, zero-sequence insulator detection technology based on in-depth learning is proposed to detect zero-value insulators with different contamination, air humidity and different locations. This technology has the characteristics of low investment cost, high accuracy and strong adaptability in complex environment, which can reduce the labor intensity and workload of power grid patrol personnel. The high accuracy of the system can effectively reduce the outage accidents caused by the deterioration of insulators in the power grid, thus ensuring the safe and stable operation of the power grid.

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