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State Identification of Insulators Flashover via Multi-Mode HMM Based on Multi-Features of Frequency Spectrum

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Abstract: As the electric power capacity and transmission voltage getting more and higher, flashover from contaminated insulators became the most serious factors affecting the reliability of high-voltage transmission system. Meanwhile, the safe operation of Chinese high-speed rails are seriously threaten by flashover, especially in haze weather. The crux to enhance the safety of power grid is to monitor and identify status of flashover by some eigenvalues. In this article, the power spectrum energy and bispectrum slices of leakage current (LC) are combined into one dimension signal through Self-Organizing Feature Map (SOM), based on which Hidden Markov Model (HMM) was constructed to recognize the state of flashover. The results show that this HMM identified flashover patterns are efficiently and successfully helpful for relevant department to make safe operation of power system.

Keywords. Power spectrum; Bispectrum slice; LC; Hidden Markov Model; State identification; SOM

INTRODUCTION

With the vigorous development of China's industrial automation, environmental pollution has become more and more intensified, meanwhile the national power grid level has increased continuously. Insulator pollution flashover has become one of the most harmful factors [1], which has seriously affected the safe operation of the power grid and the electrified railway. So far, leakage current is the most realistic evaluation criteria that can be more easily detected, which can reflect the effect of voltage, climate, as well as pollution these three factors on pollution flashover [2]. Online detection can acquire the characteristic data of natural contamination leakage current, which can provide useful information for the pollution prevention measures on spot and early warning for insulator pollution flashover risk. But because of the complexity of online environment detection and harsh change of climate, the detected leakage current signals can contain interference and noise and other useless signals, therefore, the accuracy can be greatly reduced if the leakage current is directly used as the feature vector to judge pollution flashover and risk prediction. While the spectrum feature of leakage current can well reflect the development of pollution flashover [3-5]. It is an effective method to improve the safe and reliable operation of power grid based on extracting the effective feature of leakage current, so as to have accurate identification for the status.

With the development of computer technology, the method of mode recognition has been developed rapidly. HMM (Hidden Markov Model) was a statistical probability model set up by Baum and other people at the end of 1960s, later Baker and Jelinek and other people put this theory into speech recognition, which has achieved great success, gradually it has become a mainstream technology in the field of speech processing [6,8]. In recent years, as for the application of HMM, it has been extended to other areas of the project, such as information extraction, target tracking, fault detection and diagnosis, robots as well as the identification of their characteristics and so on, which has achieved good application results [9,11].

The occurrence of high voltage insulator leakage current signal is affected by many random factors, and the effect is not so clear, a great deal of pollution flashover information is contained in signals under the statistics rule, therefore, the mature development of discriminant statistical mode recognition method, namely, HMM can more accurately identify the development status of pollution flashover [12].

In this paper, it is based on the theory of mode recognition, using the different spectrum feature of insulator leakage current to establish multi-feature fusion with multi-mode HMM, which can be used to identify the development stage of pollution flashover.

MULTI-FEATURE FUSION WITH MULTI-MODE HMM

HMM

HMM can use probability model to describe the statistical characteristics of the observation sequence, since it is with a very good mathematical structure, it can have relatively complete expression on the behavior characteristics of the observation sequence [13]. To identify the flashover state by HMM, firstly HMM must be established so as to reflect the statistical characteristics of the observation sequence of the leakage current under different status of pollution flashover, then the output probability value of the unknown observation sequence in HMM can be calculated, by comparing the output probability value of model to determine the development stage of pollution flashover, the whole process of state recognition can be shown in figure 1. As is shown, the multi-feature fusion HMM system consists of four basic modules: feature extraction, feature vector quantization, HMM training and recognition of unknown observation sequences.

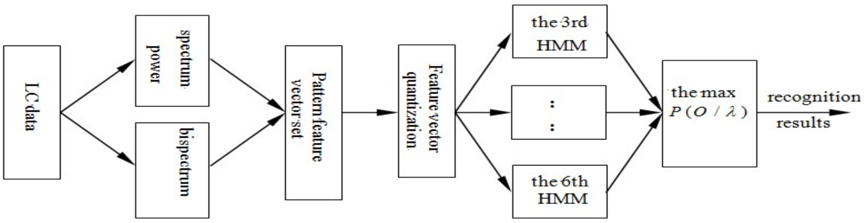

Figure 1 Multi-Feature Fusion with Multi- Mode HMM Mode Recognition

1) Feature extraction

Extracting the effective feature vector of signal, HMM can combine with different feature extraction methods to form a distinctive HMM recognition system.

2) Quantization of feature vector

The extraction of feature vector of common signal is a continuous change of physics, in order to establish the discrete HMM, it must be quantified in order to observe the discrete symbol sequences, this module needs to solve the problem of the establishment of quantizer as well as the quantization and encoding of feature vector.

3) Training of HMM

This module needs to solve two problems, one is to establish the initial model, which should determine the structure and parameters of the initial model; another is to solve the parameter optimization problem of the model, namely, when the initial model and the training observation sequence is given, how to adjust the parameter of $\lambda=(\pi,A,B)$ model, so as to make the training sequence output the maximum probability in the model.

4) Problem of recognition

As for the given observation sequence and model $\lambda=(\pi,A,B)$, solving how to quickly and effectively calculate the output probability of the observation symbol sequence, so as to make decision according to the size of the probability value to identify the recognition result of status.

SOM Vector Quantization and Coding

Vector Quantization(shorted for VQ) technology is a data compression and coding technology developed in the late 70s. It has been widely used in the field of speech and image processing [7, 9]. Vector quantization can be divided into several small regions with clustering properties by the multidimensional vector space, each region can be represented by a representative vector (i.e. code vector) so that it can effectively use various properties among the components of the vector correlation, transforming the complicated high dimensional feature vector space to one-dimensional observation symbol sequence represented by vector encoding.

In this paper, based on the characteristics of leakage current signal, the vector quantization technique can be used in the overall quantitative multidimensional feature of vector space, so as to solve encoding problem of feature vector established in HMM, and realize the features of multiple fusion and set up the development system of mode recognition of flash Discrete Hidden Markov model based on multi feature fusion.

According to the principle of vector quantization, there are two key problems to be solved when vector quantization is carried out:

1) Designing a representative code book. Namely, according to the characteristics of feature vector in the space, clustering algorithm is used to classify the training data, so that the training data can be divided into J sub-spaces, which takes the code vector as the center.

2) Quantization of unknown vectors. According to a certain degree of distortion criterion, the unknown vectors can be quantized into center code vector of each sub-space, which can take the number of code vector as the coding of unknown vector.

About these two problems of vector quantization, so far there have been a variety of algorithms [8,13], such as LBG algorithm, fuzzy vector quantization, genetic algorithm and so on. In this paper, based on the feature that random signal is with non stationary characteristics during the natural process, it proposed the method of encoding by quantifying the feature vector of the signal by using self-organizing feature map neural network SOM (Self-Organizing feature Map).

Figure 2 is the structure model of neural network of SOM [13]. It is composed by input layer and competition layer, the input layer has K neurons, which is equal to the dimension of the input feature vector that can be used to accept the inputting samples. The neurons in the competition layer can form a two-dimensional array of planar arrays, as for every input vector, through the competition algorithm in the competition layer, finally only one neuron can get excited and output the result. Network training algorithm of SOM can be shown as follows:

1) Initialization of the input neuron i to the feature map node j, namely, the weight value of w_{ij}, setting w_{ij} to be a smaller random number;

2) Inputting a new training feature pattern vector $X_i(t)$;

3) Calculating the Euclidean distance between the input mode of X_i and each output neuron j, namely, d_j:

$$d_j = \sum_{i=1}^{K} [x_i(t) - w_{ij}(t)]^2 \quad (1)$$

Selecting an output neuron $j_{\min}$ with a minimum distance as the winning neuron that can match the input pattern vector;

4) Correcting the output neuron $j_{\min}$ as well as the weight matrix of the neurons in the neighborhood:

$$w_{ij}(t+1) = w_{ij}(t) + \eta(t)[x_i(t) - w_{ij}(t)] \quad (2)$$

In the formula, $\eta(t) \in (0 \sim 1)$ is the adjustment factor of weight value, which controls the learning rate, and gradually converges to zero with the increase of time;

5) Providing new training samples continuously, repeating the third step and forth step learning process, until it can meet the requirement of the error.

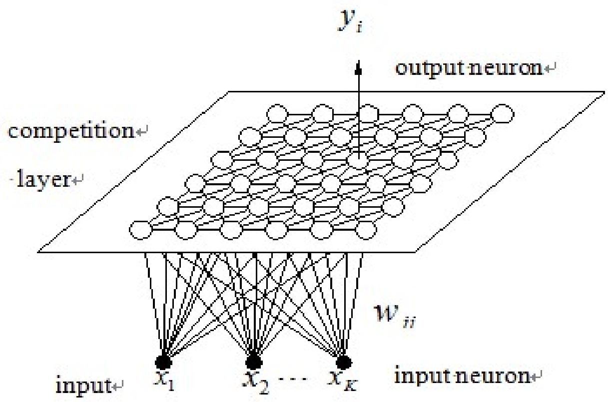

Figure 2 Structure of Neural Network of SOM

Through the training process of SOM network, it can make the similar input sample automatically cluster in the two-dimensional plane near a neuron, when it inputs a pattern vector sequence, SOM network will be matched to the nearest pattern class, and the winning neuron's serial number can be used as the code number of the input pattern vector.

EXPERIMENT AND ANALYSIS

Using the method proposed in this paper, HMM of the spectrum characteristics of leakage current of high voltage insulator can be established to identify the status of pollution flashover. The leakage current data is taken from the polluted flashover test from the following insulators test: the test adopts solid contamination layer method, constant pressure method and net spray test. The tested product is XP-70 type insulator. When the test is carried on, it adopts slow damping method to make the tested product damp, put the tested product with the electric line to the rated operating voltage, then it can start continuing humidification, until it get the flashover. The whole test process is carried out at room temperature.

Figure 3 is XP-70 type insulator pollution flashover test leakage current waveform, the corresponding salt density is 0.15 mg/cm^2, pollution degree of gray density is 2.0 mg/cm^2.

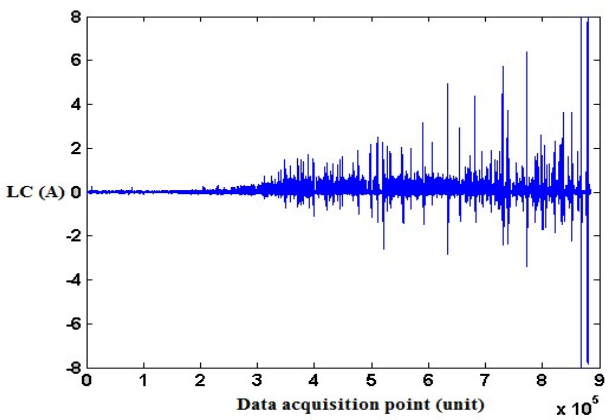

Figure 3 Leakage Current Waveform (ESDD = 0. 15 mg/ cm^2)

In the process of artificial contamination test, the whole test process can be divided into seven stages according to the existence state of arc [14], which can be shown in Table 1.

During the process of pollution test, stage seven can be quickly developed into stage eight, moreover, because of the constraint of the tested power supply capacity, when the arc is breakdown (stage 8) the transformer protection agency will quickly have action, which can make the tested voltage become zero and lead to forced extinction [14,15]. So the data obtained in the actual pollution flashover test is limited to the first seven stages. The seventh stage is in the flash phrase. In the flash phrase, the impact of current is strong, almost throughout the main arc, with a great deal of energy, moreover, the seventh stage can quickly developed into the eighth stage, so the seventh stage recognition has no meaning, for this stage is effectively predicted by the seventh stage data to predict the flashover probability (stage 8). In the first six stages, the current is relatively stable, taking into the first stage into account, it is actually a state of the tested insulator before moisture, when the surface of pollution layer can keep higher electrical strength, the leakage current is smaller, and its essence is corresponding to the normal working state of the insulators, thus there is no need to discuss it. The second stage belongs to the glow discharge stage, the discharge can have up volt ampere characteristic, which has no harm to the insulation movement [3, 16], from the engineering point of view, there is no need to discuss it. Therefore, in this paper, it only discusses from the third stage to the sixth stage.

Table 1 process of XP-70 insulator contamination test

Discharge stage	Discharge features
1	No obvious discharge phenomenon
2	Purple spark, light purple filamentary shape discharge, with weak sound
3	Purple brush shape discharge, yellow, white small spark
4	Orange short arc, pulse high density, discharge duration, with large sound
5	Pulse frequency is reduced, 1/3 leakage distance
6	Pulse interval is lengthened, bright orange red main arc, the dense small arc is inside the groove
7	Strong discharge, almost through the leak distance, still able to withstand
8	Red arc, may occur flashover at any time

Because of the complication of online detecting environment of leakage current and change of the harsh climate, the detected leakage current signals contain interference and noise and other useless signal, etc., plus the comprehensive influence of temperature, humidity, pollution and other factors on the leakage current, it can not have the integrity and accuracy feature to carry on pattern recognization by adopting the single feature value, so it can adopt multiple model of pollution flashover state HMM for pattern recognization. Its process can be shown as follows:

1) Establishing HMM of pollution flashover under stage 3 to stage 6;

2) Inputting each HMM of leakage current observation sequence under the unknown state, calculating the probability output value of the observation sequence under each model;

3) Taking the model with the maximum probability output value as the matching model of the observation sequence, and its corresponding state is the state of the current leakage current observation sequence.

According to the above steps, firstly it can extract selected power spectral energy and the peak value of the maximum spectrum feature value of bispectrum diagonal slice from the spectrum feature value of the leakage current signal. And then it can extract 600 such feature vectors to form two-dimensional pattern space from the four stages, namely from stage 3 to stage 6. Figure 4 is the result of training SOM network with 6×6 array by adopting these feature vectors. Therefore, 36 basic code vector can represent the feature vector cluster in the model of spatial information, then it can encode these 36 code vectors (or neurons), which can complete the establishment of SOM quantizer.

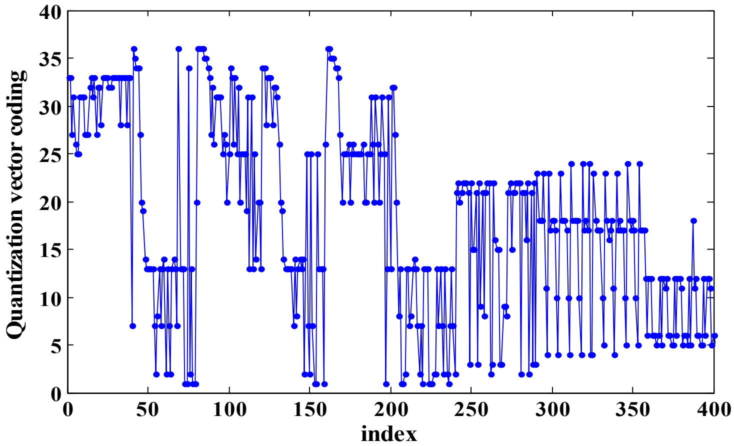

Figure 4 Quantization Result of Feature Vector

Secondly, establishing five HMM corresponding to the feature vector, these five models can be numbered as 3: stage 3 is in stage with small spark; 4: stage 4 is in stage with short arc; 5: stage 5 is in stage with 1/3 leakage distance of arc; 6: stage 6 is in stage with orange main arc.

Thirdly, by using the feature vector of each stage to train the establishment of HMM: namely, calculating the probability value of the logarithm of the sample sequence generated in each iteration new model. With the increase of the number of iterations, the output probability value of the model can be increased gradually, after a certain number of iterations, the model can enter into the convergence saturation state, the output probability value is almost no longer increased, at this time HMM model training can be finished.

In this paper, by using six states, each state after developing structure can be as the model structure of HMM of pollution flashover state, and the training data are obtained from 400 feature vector quantization sequences of each stage of pollution flashover with the same artificial pollution test.

In order to verify the effectiveness of the adopted HMM method, using the trained HMM to identify training data. Figure 5 is the result. It can be seen from the figure, the log probability value is very close to 0, when the log probability value is equal to 0, it can indicate that pattern recognization is in the probability of 100%. Since the logarithm of probability value 1 is 0, while the logarithm of probability value that is less than 1, its result must be less than 0, the smaller the logarithm of probability value is means smaller occurrence of the probability. Therefore, from Figure 4, the established HMM have a good recognition performance.

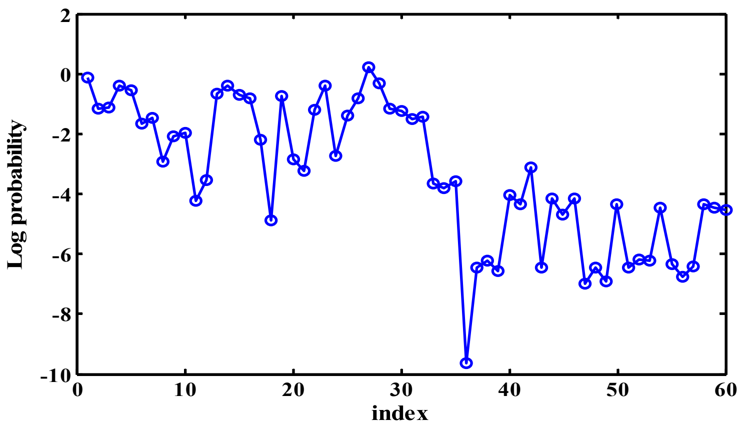

Figure 5 Result of Training Data Identified by HMM

Finally, the recognition sequences can be input into the trained HMM, taking 5000 data each as one time interval, so as to calculate out the final result of identification.

Table 2 shows the probability output value of partial unknown observation sequence in the four model in the development process of pollution flashover, the output value of the corresponding model in four stages of development of pollution flashover can be compared among them, the corresponding model number of the maximum probability value (in Bold) is the result of identification. Taking the second data as an example, the output probability value of an observed sequence in the four model is respectively (-121.76, -145.29, -220.62, -307.16), among them,the maximum value is -121.76, which is corresponding to stage 3, thus the result of identification is "3". Figure 6 can reflect this result intuitively.

Table 2 Partial Data of Identification Result of HMM Feature and Spectrum Feature

Data segment	1	2	3	4	5	6	7	8	9
Stage 3	-250.7	-121.7	-109.9	-177.2	-129.1	-180.0	-180.1	-164.1	-154.7
Stage 4	-201.6	-145.2	-171.3	-149.2	-165.1	-189.3	-191.5	-160.6	-146.3
Stage 5	-383.5	-220.6	-275.8	-237.8	-232.1	-215.3	-196.1	-219.9	-252.5
Stage 6	-451.2	-307.1	-29.48	-28.4	-305.2	-242.9	-201.8	-218.4	-230.7
Result of identification	4	3	3	4	3	3	3	4	4

As is shown in Figure 6: during the process of pollution flashover, with the surface layer of the pollution surface is full of wet, the spark discharge can be changed into a small arc, pollution flashover then developed into stage 4. Small arc discharge leads to leakage current that can occur larger impact, but because the strength between the small arc discharge has little difference between each other, at the same time there can be several small arcs to discharge, so the discharge impact can have offsetting trend, at this time, the leakage current shows a certain fluctuation [17]. When the voltage is zero, it is possible to put out a very small arc, then the development of the pollution flashover can be restored to stage 3 with spark discharge [3]. The corresponding mode recognition is also transferred from stage 4 to stage 3. When the pollution flashover is developed into the later stage, the orange red main arc (stage 6) may be transferred into one third distance of leakage arc due to various reasons (stage 5). The whole result of identification is in good agreement with the development of pollution flashover, which shows the validity of using HMM to identify the development status of pollution flashover.

CONCLUSIONS

1) By adopting SOM vector quantization method to quantify the spectrum feature vector of multidimensional leakage current, it can solve the problem of coding of multi-feature fusion and observation feature vector.

2) By using the spectrum method to extract the effective feature of the leakage current, a multi-mode and multi-feature fusion HMM can be established, and the development stage of pollution flashover can be identified. The result showed that the difference of probability output value in each HMM by using the unknown observation sequence can reflect the matching degree of the observation sequence and model, four kinds of typical pollution flashover development stage under HMM can successfully identify the different stages of the pollution flashover.

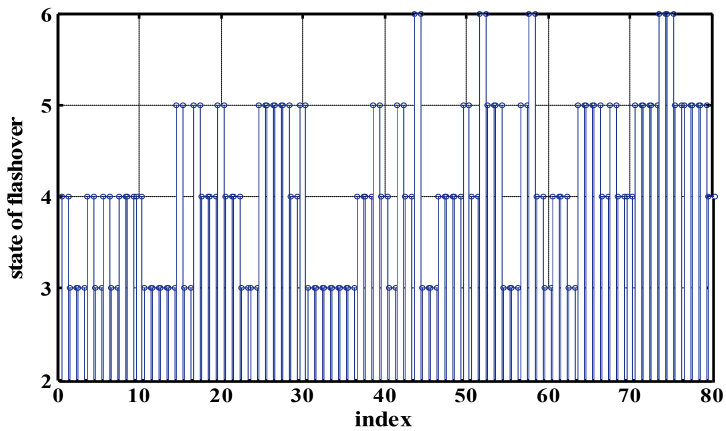

Figure 6 Identification Result of Pollution Flashover Development of Multi Model HMM with Spectrum Feature Fusion

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