EVALUATION OF INSULATOR STRING'S ICING STATUS BASED ON LEAKAGE CURRENT

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Abstract: This paper studied the leakage current of insulator strings applied with operating stress during icing regime and evaluated the insulator string's icing status based on leakage current characteristic. Artificial icing test were conducted on one kind of widely used ceramic insulator. Leakage current waveforms of the insulator string during the icing regime were recorded by leakage current monitoring system. The relationship between the maximum leakage current and the icing duration was studied. Power Spectral of the maximum leakage current series of every 20 minutes were analyzed. It was found that the power spectral of principal frequencies such as 50 Hz, 150 Hz and 250 Hz rise with the icing duration and relate closely to the icing thickness on insulator strings. Fitting curves of the power spectral density with the icing duration were given. It provided a good approach to evaluate the insulator strings' icing status.

1 INTRODUCTION

In the late winter and early spring, transmission lines in many places in the south of China are subject to flashovers induced by freezing rain. At that time, the high humidity and large amount of rainfall due to the frequent collisions of warm and cold currents under low temperature could last for a long time. Sometimes when it becomes serious the insulator strings may be coated with ice and bridged by icicles, which significantly reduce the insulation strength and lead to flashovers. Glaze ice with the density of 0.8-0.9 mg/cm^3 can easily form on insulators on freezing rain conditions. Glaze ice poses the greatest danger to the insulators due to its great hardness and density [1]-[11].

Leakage current of icing insulator strings has a close relationship with the insulators icing status. It is quite convenient to monitor leakage current on line, and it is helpful to investigate the relationship between leakage current and the icing status. CIGRE recommended two main leakage current approaches: the pulse approach and the maximum value approach. However, it is difficult to provide useful prediction of the icing status by the pulse approach and the maximum leakage current. Leakage current is a kind of power signal, and it may provide some useful information of the icing status when analyzing power spectral of the leakage current series where the maximum leakage current appears during every interval.

2 TEST SETUP

2.1 ICING CHAMBER

The test was conducted in an artificial icing chamber presented in Figure 1. The icing chamber is a cylinder tank with the interior height 7m and the diameter 4m. The support system has refrigeration, vacuum, spray and other functions. Refrigeration system is able to adjust the temperature from 0~-19°C. Insulator string hangs in the centre of the climate room for icing test. On the wall in the opposite directions are two lines of sprayers from top to bottom. The angle between the spray direction and the insulator string is 45°.

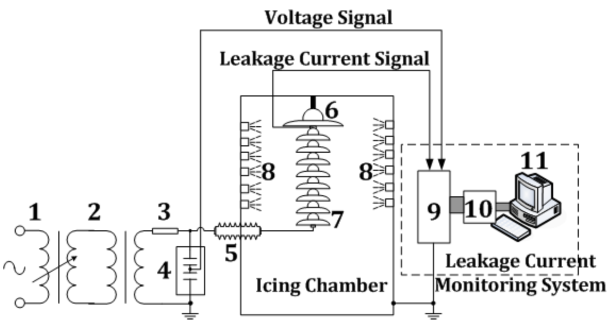


Figure 1. Schematic diagram for the HV circuit and leakage current monitoring system

(1)Voltage regulator: 6.3 kV/6.3 kV, 2500 kVA, (2) Transformer: 6 kV/750 kV; (3) Protective resistor: 10 kΩ, (4) AC voltage divider, (5) Bushing, (6) Clean insulator, (7) Specimen insulator string, (8) Nozzles, (9) Leakage current and voltage sensor, (10) DAQ, (11) PC.

The water intended for icing was prepared to the set conductivity through the mixture of de-ionized water and tap water. After pre-cooled to 0~4°C by the refrigerator the water was then pumped into the artificial climate room and sprayed onto insulators. The precipitation amount could be controlled by adjusting the work cycle of the pump.

Table 1. Ice accumulation test parameters

Parameter	Value
Ice accumulation type	Wet-Grown
Temperature in °C	-7
Rainfall in l/h/m^2	70
Average water drop diameter in μm	100-200
Freezing water conductivity in μs/cm @ 20°C	100
Spraying angle in °	45
Wind speed in m/s	2-3
Applied voltage in kV	63.5

Wet-grown glaze ice is the most dangerous form of ice accumulation to cause insulator flashover. The parameters adopted in the test in Table 1 fit the recommendations given by IEEE [3]. In order to increase the ice accumulation efficiency, the water was sprayed for 15s every 2 minutes.

2.2 SPECIMAN INSULATORS

Table 2. Parameters of the test insulator XP3-16

Parameter	Value
Structural height in cm	15.5
Diameter in cm	28
Creepage distance in cm	35
Surface area in cm^2	2075
Ice thickness on the monitoring cylinder in mm	15

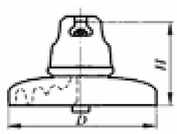


Figure 2. Profiles of the tested insulators XP3-16

The insulators were pre-contaminated with kaolin as the non-soluble contaminant and NaCl as the soluble contaminant. The NSDD of the insulator string is 0.5 mg/cm^2 and ESDD is 0.05 mg/cm^2. 8 insulators as a string was suspended in the icing chamber and applied with the operating voltage 63.5 kV to simulate the insulator string used in 110 kV transmission lines. Before icing progress, to prevent the contaminants from washing down by the water, a small amount of water was sprayed to form a thin layer of icing on the insulators.

2.3 LEAKAGE CURRENT MONITORING SYSTEM

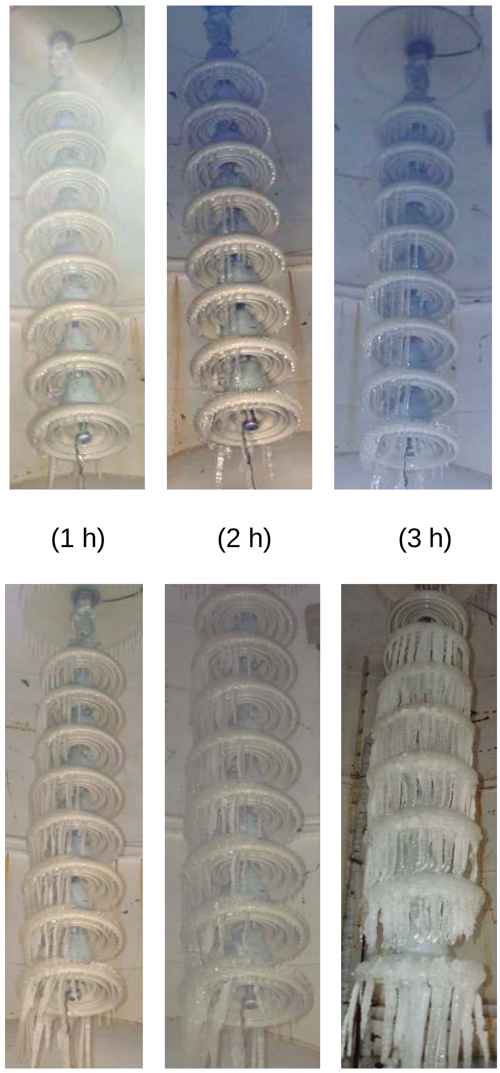
Leakage current monitoring system was used. The leakage current is recorded on a computer through an NI data acquisition card controlled by LabVIEW software. It is able to make accurate measurement of the leakage current value with a 5000/s sampling rate. The leakage current obtained during the ice accretion process is quite helpful in analyzing the insulators' icing status.

2.4 POWER SPECTRAL ANALYSIS

Leakage current is a random signal and there is no explicit mathematical expression. However, some useful rules of leakage current may be obtained by estimating the power spectral of the leakage current through limited leakage current signal. Modern power spectral estimation, which is one of the most widely useful algorithm, is to estimate the parameter model through observed data and then estimate the power spectral. In this paper, Auto Regressive (AR） model was used to analyze the power spectral of leakage current signal samples. The power density of the leakage current in the frequency domain is obtained.

3 RESULTS AND DISCUSSION

3.1 THE ICING STATUS



(1 h) (2 h) (3 h)

(4 h) (5 h) (6 h)

Figure 3. The icing status of the insulator strings. Photos were taken every hour.

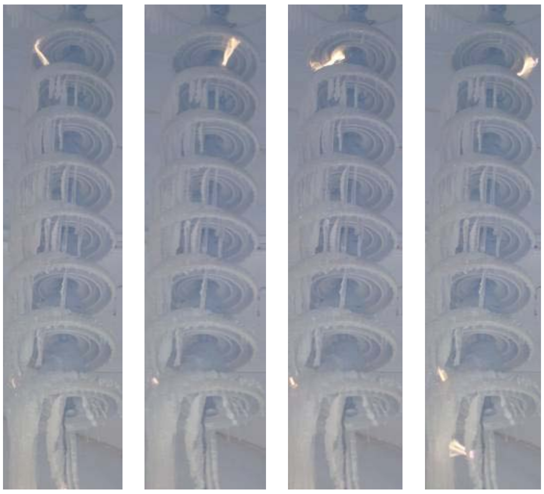


Figure 4. Discharge of the insulator strings. Photos were taken at the sixth hour when the discharge is serious.

During icing regime, freezing water was sprayed for 15s every 2 minutes. In this way, the glaze ice may be effectively coated on the insulator strings. Photos of the insulator string presented in Figure 3 was taken every hour. Glaze ice was gradually coated. At the end of the sixth hour, the icing was the heaviest. Discharge always happened at the stage of water spray. Figure 4 was taken at the sixth hour when the discharge is serious. There were dramatic bright arcs floating across the insulators both at the high voltage terminal and the ground terminal. The insulator string may flashover when the glaze ice was sufficiently coated.

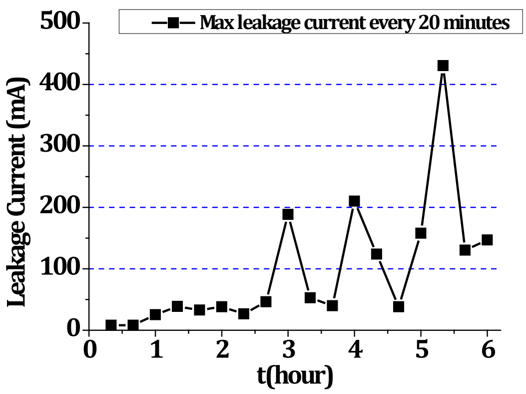


Figure 5. The maximum peak value of leakage current every 20 minutes.

As the icing time increased, the discharge became more serious and the leakage current became larger. At the beginning of icing regime the maximum leakage current was about several mA, while during the sixth hour, the maximum leakage current increased to 450 mA, which is serious discharge and couple with dramatic bright arcs. It was not far from flashover. The waveform of the leakage current was detailed recorded through the leakage current monitoring system. The sampling rate is 5000/s and the frequency of the applied voltage is 50 Hz, so in a power frequency cycle 100 point of the leakage current was sampled. It was enough to use these sampled data to do analysis on the low-frequency characteristics of the leakage current.

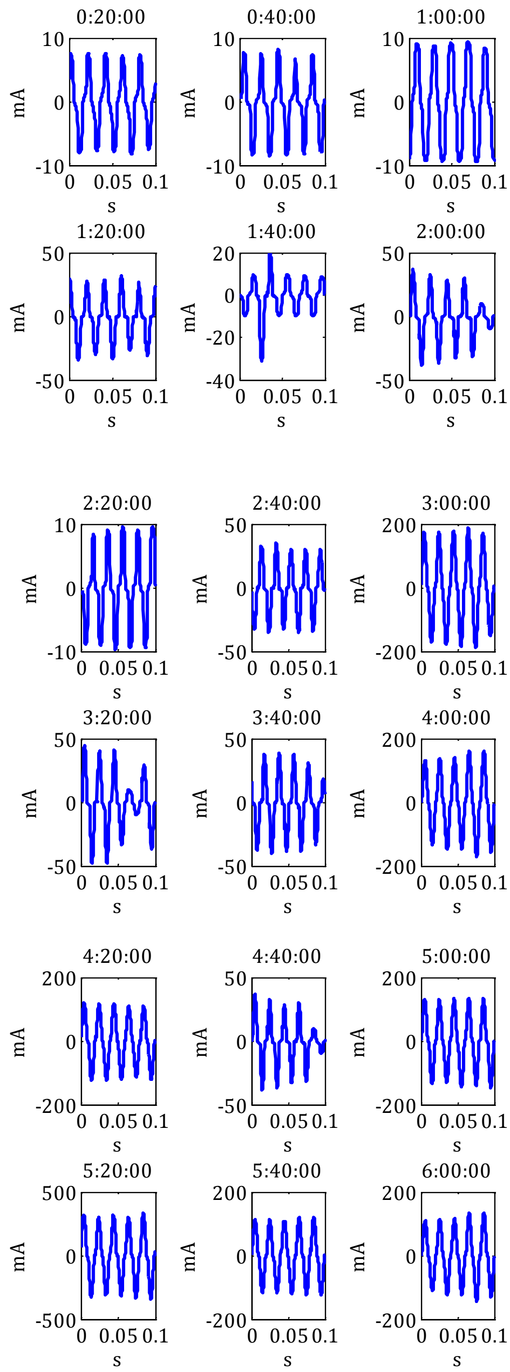


Figure 6. The waveform of the maximum leakage current in every 20 minutes. Five wave cycles in 0.1s in which the maximum peak value of the leakage current appeared were presented.

As to the limit of space, only five cycles of the leakage current was presented in Figure 6. The waveforms were selected from leakage current series in which the maximum leakage current of every 20 minutes appeared. Leakage current is a random power signal. It is hard to get quantitative information of the relationship between the leakage current and the icing status if only the maximum leakage current value was used because of its randomness.

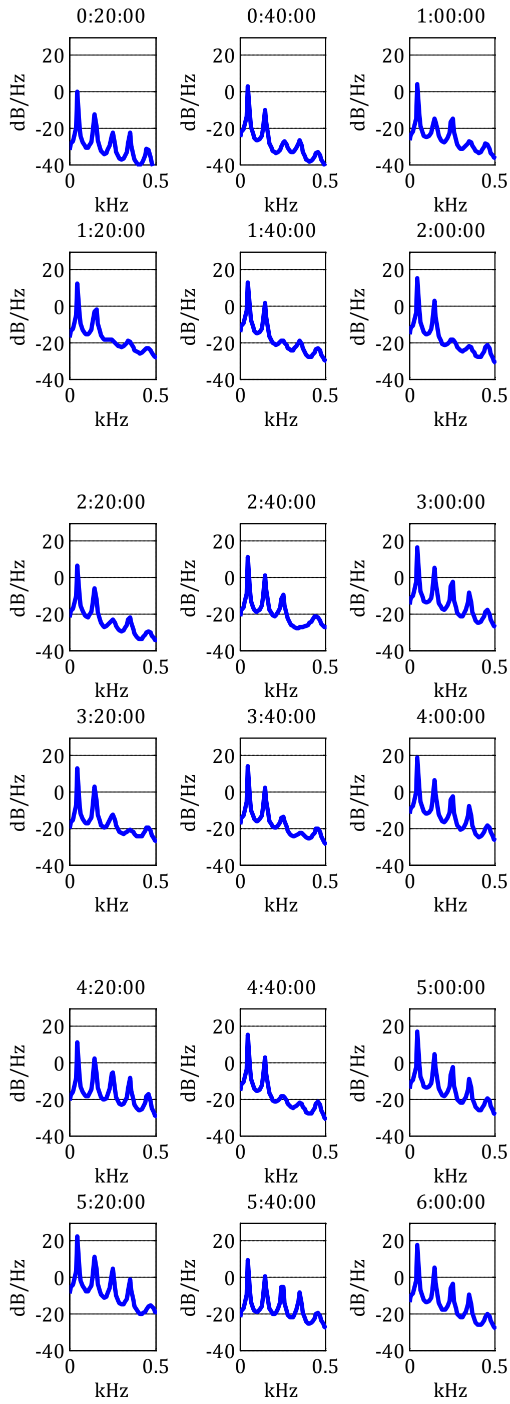


Figure 7. The power spectral of 40 leakage current wave cycles during which the maximum peak value of the leakage current appeared in every 20 minutes were analyzed through AR model. The power spectral density has obvious peak value at the frequency of 50 Hz, 150 Hz and 250 Hz, corresponding to the fundamental, third harmonic and the fifth harmonic components.

However, when more leakage current cycles during which the maximum leakage current appeared were considered, the information of the relationship between the leakage current and the icing status may become more stable and quantitative. Figure 7 presented the power spectral analysis of the leakage current in every 20 minutes. The power spectral density at the frequency of 50 Hz, 150 Hz and 250 Hz was obtained and presented in Figure 8. The power spectral density of 50 Hz, 150 Hz and 250 Hz increased with the ice accumulation time, although there was small fluctuations.

The power spectral density of 50 Hz usually fluctuates between 10 and 20 dB, when it was larger than 20 dB, there was serious discharge and dramatic arcs across the insulators. It may be close to flashover. The linear fitting curve of the 50 Hz power spectral density and the time of ice accumulation is y_{50}=2.34t+5.05, where y_{50} is the 50 Hz power spectral density and t is the time of ice accumulation . As the ice thickness on the rotating cylinder was 15mm after six hours' icing, the fitting curve of the 50 Hz power spectral density and the ice thickness is y_{50}=0.936x+5.05, where y_{50} is the 50 Hz power density and x is the ice thickness in mm.

The power spectral density of 150 Hz usually fluctuates at 0-5 dB. , when it was larger than 5 dB, there was serious discharge and dramatic arcs across the insulators. It may be close to flashover. The linear fitting curve of the 150 Hz power spectral density and the time of ice accumulation is y_{150}=2.92t-8.94, where y_{150} is the 150 Hz power spectral density and t is the time of ice accumulation. The fitting curve of the 150 Hz power spectral density and the ice thickness is y_{150}=0.936x-8.94, where y_{150} is the 150 Hz power density and x is the ice thickness in mm. As the power spectral density of 250 Hz is so tiny, this kind of signal is of less value.

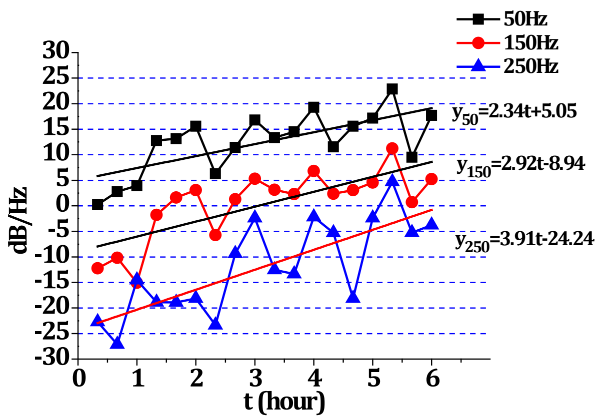


Figure 8. The power spectral density at the frequency of 50 Hz, 150 Hz and 250 Hz. These value was obtained from Figure 7.

4 CONCLUSIONS

Six hours of ice accumulation was conducted in the artificial icing chamber. The leakage current during the icing regime was recorded in leakage current monitoring system at the sampling rate of 5000/s. 40 leakage current cycles during which the maximum leakage current appeared were used to do power spectral density analysis. Several results were obtained as follows:

1. The linear fitting curve of the 50 Hz power density and the time of ice accumulation is y_{50}=2.34t+5.05, where y_{50} is the 50 Hz power spectral density and t is the time of ice accumulation . The fitting curve of the 50 Hz power spectral density and the ice thickness is y_{50}=0.936x+5.05, where y_{50} is the 50 Hz power density and x is the ice thickness in mm.

2. The linear fitting curve of the 150 Hz power density and the time of ice accumulation is y_{150}=2.92t-8.94, where y_{150} is the 150 Hz power spectral density and t is the time of ice accumulation. The fitting curve of the 150 Hz power spectral density and the ice thickness is y_{150}=0.936x-8.94, where y_{150} is the 150 Hz power density and x is the ice thickness in mm.

The relationship between the 50 Hz, 150 Hz power spectral density and the icing time and ice thickness are of value to monitor the field operation during ice accumulation weather.

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