วิศวกรรมสาร มข. ปีที่ 38 ฉบับที่ 3 (297 -304) กรกฎาคม – กันยายน 2554 บทความวิจัย

KKU Engineering Journal Vol.38 No. 3 (297 -304) July – September 2011

A comparison on leakage current of 22 kV porcelain insulator by using rotating wheel tester with high voltage AC and impulse voltage excitation

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Abstract

This paper describes the leakage current (LC) on pin type porcelain insulator surface evaluated by the rotating wheel tester. The experiments, which were at High Voltage Laboratory, Faculty of Engineering, Khon Kaen University, Thailand, has been studied under the condition of environment damage with surface contamination of specimen and then excited by electrical stresses for aging. The experiments were divided in two cases – high voltage alternating current (HVAC) and HVAC alternating with impulse excitation voltage. The experimental results show that the LC on specimen surfaces for both cases gradually increases almost the same results for the first 100 cycles after that it rapidly increase with rotating wheel more than 100 cycles. Above 315 cycles, the LC is obviously different in both cases.

Keyword: insulator leakage current, HVAC and impulse aging, rotating wheel tester.

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1. Introduction

Outdoor insulators are important equipment in overhead transmission lines and substations. The performance of them in outdoor applications is greatly influenced by the action of various environmental parameters. They always suffer in severe conditions such as surge lightning, electrical stresses, pollution and dust. The contaminants on the insulator surface that is as a dry layer; it becomes conductive when it exposes to the light rain or morning dews (Limbo 2009). A flashover can be occurred in this case even though operations are under the normal voltage stress. Consequently, power outage will be often followed for a long time. In addition, the influence of pollution is one of the important parameters to be considered to develop the quality of power transmission line.

Currently, there are many experiments for evaluated characteristics of porcelain insulator that depends on the environment. (Limbo 2009) reported the characteristics of insulators in two series - the first series was carried out by HVAC and the second series was positive and negative polarity high voltage direct current (HVDC) excitation. The results shows that the leakage current (LC) was difference levels depend on type of excitation. (Yin Yu et al) presented the LC on their experiment after 31500 cycles test with the electric stress of 35 V/mm and salinity of 1.4 ± 0.06 g/ℓ. The results show that LC does not increase linearly and the non-uniform electric field distribution caused by the insulators' structure has large effect on the growth of erosions and tracking. (Zhou and Mao) presented their experiments on rotating wheel dip test (RWDT). It had been done under wet test for four days and dry test for one day. The results showed that specimen's surfaces have no obvious crack and dilapidation, even though, there are many electric activities passed the surface. (Han-Goo et al) tested insulators by RWDT with flashover test and impulse test after aging test. The results show erosion occurred in parting line on the surface of insulator. (Amnart Suksri et al) investigated on LC of 4 type porcelain surface insulators by using a RWDT, with varied the saline conductivity and high voltage excitation. Results show the LC had been relationship with saline conductivity and rate of excitation voltage. The less LC had been occurred on pin type insulator surface.

This research is evaluating the effective of HVAC 22kV and impulse excitation voltage on 22 kV porcelain post type insulators by using rotating wheel tester. The LC on specimen surface has been concentration.

2. Failure mode of insulator

High voltage outdoor insulators are suffering from electrical stresses and exposed to pollution (Gençoglu and Cebeci) because of salt in the regions close to the sea, pollution from build and chemical residues in the industrial regions. The pollution will increase the conductivity on the surface of insulator and cause to decreases the flashover performance, finally, causes to the breakdowns on normal frequency power system.

2.1 The pollution flashover

Wind, dust, rain, salt humidity, fog, solar radiation, snow and ice, lightning and air density are significant impacts on the electrical and/or mechanical performance of high voltage insulators.

These factors can change the insulating material physically by roughening and cracking; and chemically caused by soluble of salts, acids and other deposited on the surface (Kuffel and Kuffel). Surfaces become hydrophilic and water p
in the insulating materials causing breal
normal condition (Claude et al).

The pollution flashover consists of three main phases (Gençoglu and Cebeci):

1. Formation of conductive pollution film:
    a. Covering of insulator surface with pollution layer.
    b. Wetting of pollution layer by humidity.
2. Formation pre-discharge along dry band.
3. Propagation pre-discharge along dry the surface and short circuit.

2.2 The leakage current and flashover equation

The increasing leakage current value depends on accumulation of contamination on insulator surface and humidity from fog, light rain, etc. The discharge may be occurred from this effect (Holtzhausen and Vosloo).

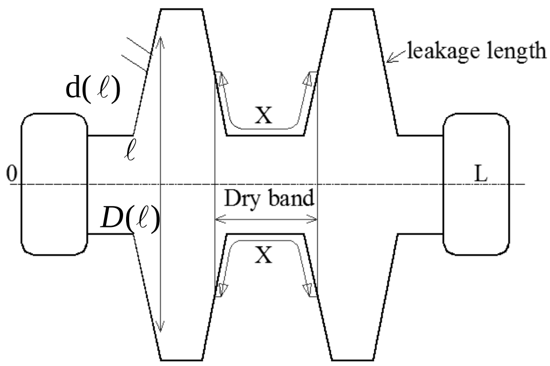


Figure 1. Model of insulator and leakage current on the surface

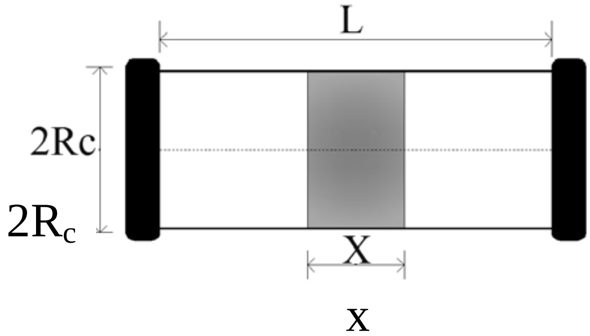


Figure 2. Equivalent cylindrical of insulator.

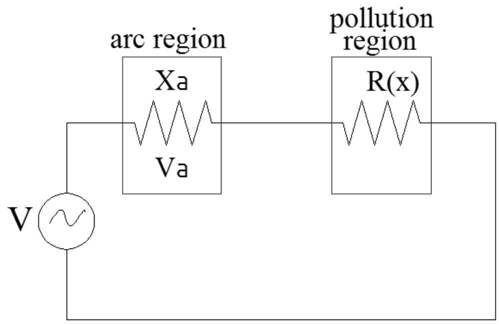


Figure 3. Equivalent circuit of insulator surface on contamination and arc area.

The Kirchhoff voltage equation for equivalent circuit is presented by:

$$V = V_a + R(x)I \,. \tag{1}$$

Term of V_a and $R(x)I$ indicate the voltage drops across the dry band discharge and the series pollution surface resistance, respectively.

$$V_a = AX_a I^{-n} \tag{2}$$

$$X_a = k_a X \tag{3}$$

Where A and n called the discharge constant depend on the atmosphere in which the discharge burns. For arc in air and atmosphere of stream, A is 63; 518 and n is 0.7; 0.275, respectively (Gençoglu and Cebeci).

And

$$R(x) = \frac{L-X}{2\pi R_c \sigma_s} = \frac{(L-X)F}{L\sigma_s} \tag{4}$$

So,

$$R_c = \frac{L}{2\pi F} \quad (5)$$

$$F = \int_0^L \frac{d\ell}{\pi D(\ell)} \quad (6)$$

Usually, form factor (F) depends on the geometrical of the insulator.

Where x is the dry band length, X_a is the arc length, V_a is the arc voltage, R_c is cathode resistance, k_a is arc length factor and σ_s is surface conductivity (Micro-Siemens, µS), $D(\ell)$ is varies diameter of insulator which depend upon its shape.

Term of L - X is the length pollution resistance in series with the dry band discharge. Combining Equation (1) to (4), we get

$$V = Ak_a X I^{-n} + \frac{(L-X)IF}{L\sigma_s} \quad (7)$$

The leakage current (I_L) during an arc free period can be calculated by:

$$I_L = \frac{V(t)}{R_L} \quad (8)$$

Where $V(t)$ is the sinusoidal line to neutral. The surface resistance is calculated from the form factor:

$$R_L = \frac{1}{\sigma_s} F \quad (9)$$

From equation (9), the surface resistance depends on the shape of insulator, as represented by form factor and the pollution dampness distribution on the insulator surface.

3. Experiment setup

3.1 Rotating wheel dip test

The rotating wheel dip test (RWDT) is one of methods to accelerate the aging insulator technique. In this experiment, the RWDT rotates in 4 steps and 40 seconds at each position.

1. The first position: specimen is dipped into saline water.

2. The second position: specimen is at horizontal position after dip into saline water. The water will be dripped off as a consequence of hydrophobicity.

3. The third position: specimen has been excited by electrical stresses.

4. The fourth position: specimen rests at a horizontal position.

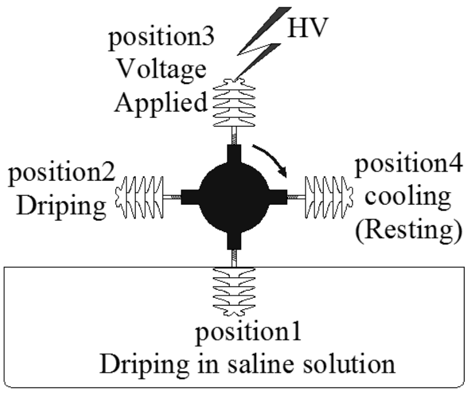


Figure 4. Rotating Wheel Dip Test

Specially, there are 2 excitation voltage types like high voltage alternation current (HVAC) and high voltage negative polarity impulse. They alternate to excite every 20 cycles. The leakage current had been recorded when HVAC excites to specimen.

The power frequency single-phase transformer had been carried out for excitation insulator on HVAC ageing. The capacity of transformer is 10 kVA voltage ratio 220/33,000 V, at 50 Hz, which output voltage will be performed by a control of the primary or low voltage input of the voltage step-up systems and impulse high voltage generation 145 kV 2.5/50 µS, which discharge of impulse controls by d.c. source. The wave shape as shown on Figure 5.

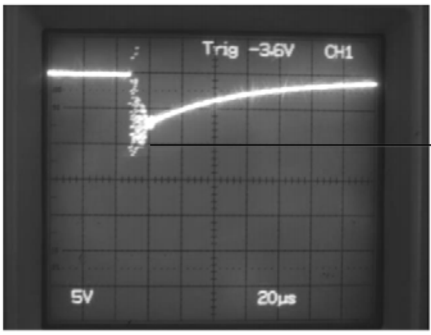


Figure 5. The wave shape of Impulse excitation voltage.

3.2 Experimental arrangement

Main equipments were arrangement set up as show on Figure 6 and 7.

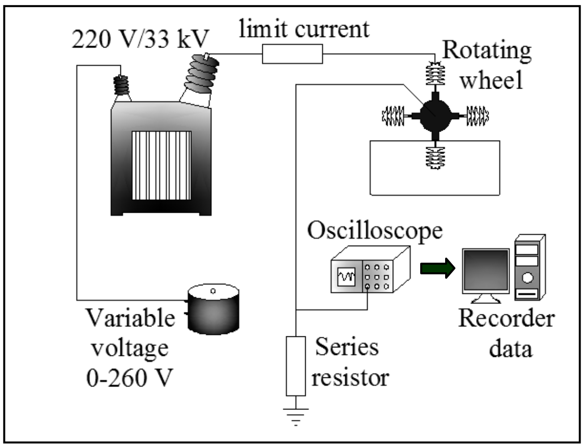


Figure 6. HVAC excitation voltage equipment set up.

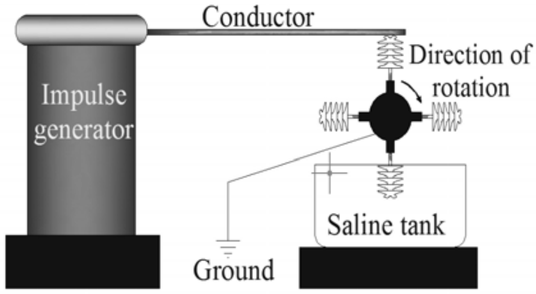


Figure 7. HV impulse excitation voltage equipment set up.

3.3 Test condition

In this research, there are two experiments; both of them are the same contamination condition. All specimens dip into NaCl solution with 0.5 mS/cm for rotating wheel speed of 160 s/cycle. But they are different on excitation voltage that are:

Case 1: HVAC 17.9 kV excitation voltages.

Case 2: HVAC 17.9 kV alternate with impulse negative polarity 1.2/50 µSec, 110 kV excitation voltages.

4. Specimen

Post type porcelain insulators for application on 22 kV transmission line has been carried out for this experiment. The resistance on contamination surface specimen is calculated by equation (9).

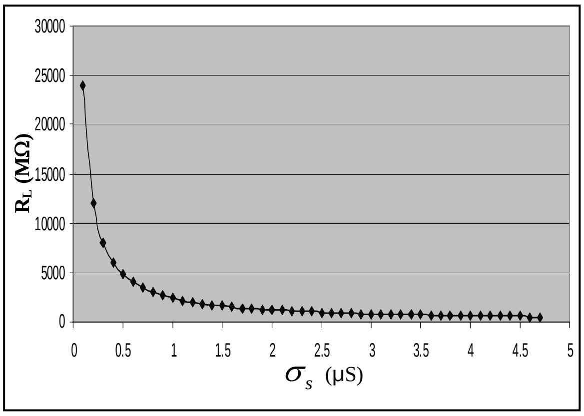


Figure 8. The resistance of specimen on contamination condition.

5. Experiment and result

The experiment had been done at High Voltage Laboratory, Khon Kaen University. The experimental has been processed in four days. The leakage current was recorded by digital camera and computer.

The results on the first 100 cycles, leakage current (LC) is less than 1 mA on wet condition. Both cases gradually increase almost the same trend. However, LC rapidly increases when it is over 1 mA or after 100 cycles. They show the different effect after 315 cycles as shown in Figure 9 - 13.

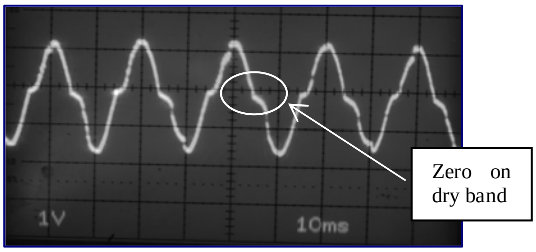


Figure 9. Waveform of leakage current on case 1.

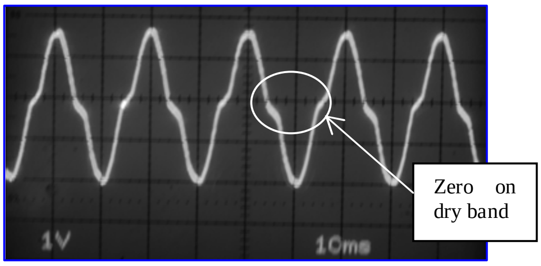


Figure 10. Waveform of leakage current on case 2.

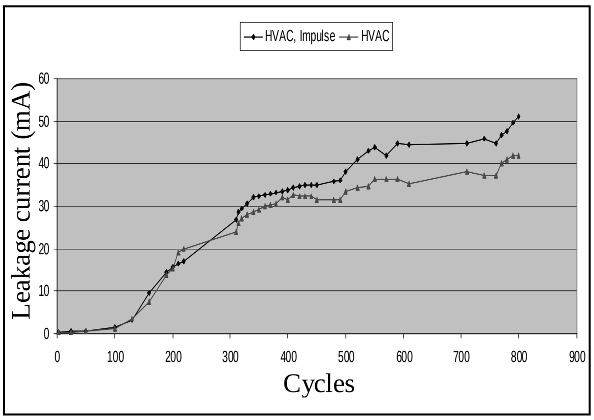


Figure 11. Leakage current from experimental

From experimental results, there is the partial discharge at dry band of insulator and it generates the sound. The distortion waveform of leakage current due to partial discharge is shown in figure 9 and 10.

Increasing leakage current due to degradation of specimen surface indicates the decreasing surface resistance which is calculated by equation (8).

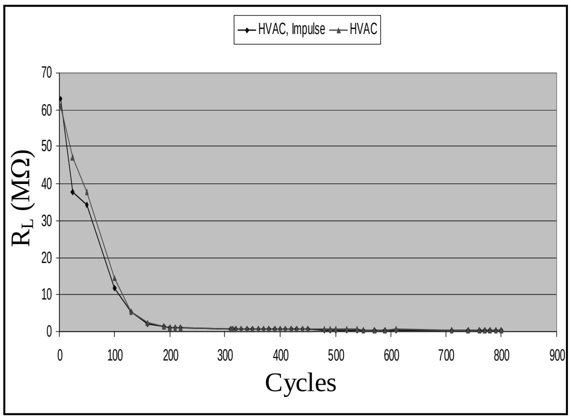
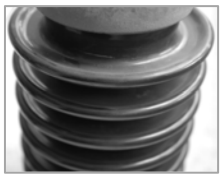


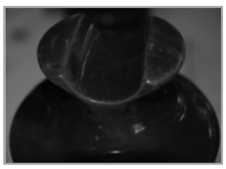
Figure 12. Resistance surface of insulators vs cycles.

In addition, the specimen surface can be observed after experiments as shown in figure 13.

(a) Chalking



(b) Discoloration



(c) Crazing

Figure 13. Insulator surface after experiment.

6. Discussion

The LC as results in section 5 is obtained by means of the voltage drop across a resistor connected in series with each specimen. It indicates the degradation of insulator surface which is caused by electrical stresses on contamination surfaces. We have found that the insulator surface losses hydrophobicity (Claude de Tourreil, Wallace Vosloo, Franck Schmuck) which express in term of appearance chalking, discoloration and crazing as shown in figure 13. In addition, the peak LC occurs at the initial excited voltage and decreases after 20 seconds that presents a low surface resistance on wet condition.

At initial state, LC gradually increases because of LC less 1 mA on wet condition and it is not enough to aging surface and the saline resistance layer has not yet formatted completeness in this period. The LC rapidly increases because of cumulative surface contamination. The discharge is continuous on dry bands after that it may be burn continuously and extended along the surface of the insulator. Consequently, it leads to decrease surface resistance in series with the dry band discharge.

The different results from two cases might be contributed by the impulse effect when insulator surface covers by saline layer. It is severe effect of insulator on impulse more than high voltage AC excitation voltage.

7. Conclusion

The aging on HVAC and HVAC alternate with impulse on contamination porcelain surface has been carried out. Degradation on porcelain surface insulator with negative polarity impulse excitation is higher than high voltage AC excitation voltage. The extension of dry band area due to partial discharge accelerates the aging when specimen is excited by HVAC or impulse excitation voltage.

Acknowledgements

The authors would like to thank for Khon Kaen University scholarships and Khon Kaen University's Graduate Research Fund Academic.

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