International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:3, No:10, 2009

Difference of Properties on Surface Leakage and Discharge Currents of Porcelain Insulator Material

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***Abstract*—**This paper presents the experimental results of comparison between leakage currents and discharge currents. The leakage currents were obtained on polluted porcelain insulator. Whereas, the discharge currents were obtained on lightly artificial polluted porcelain specimen. The conducted measurements were leakage current or discharge current and applied voltage. The insulator or specimen was in a hermetically sealed chamber, and the current waveforms were analyzed using FFT.

The result indicated that the leakage current (LC) on low RH condition the fifth harmonic would be visible, and followed by the seventh harmonic. The insulator had capacitive property. Otherwise, on 99% relative humidity, the fifth harmonic would also be visible, and the phase angle reached up to 12.2 degree. Whereas, on discharge current, the third harmonic would be visible, and followed by fifth harmonic. The third harmonic would increase as pressure reduced. On this condition, the specimen had a non-linear characteristics.

***Keywords*—**leakage current, discharge current, third harmonic, fifth harmonic, porcelain.

I. INTRODUCTION

PORCELAIN is one of most important matter of outdoor insulator. Several flashovers are occurred on porcelain insulators due to some factors. However, they are supposed mostly to be caused by pollution of salt. Despite the extensive investigations carried out on the pollution performance of outdoor insulator, the flashover characteristic and its interaction with insulator shape is still not very well understood [1].

When the surface of an energize insulator is covered with a conducting pollution layer, surface leakage current will flow leading to dry bands formation in the regions of high current density and low wetting. Consequently, the voltage redistribution along the insulator increases the stress across the dry bands resulting in partial arcs. These are will burn in series with the wet surface resistance. If this resistance is sufficiently low, the partial arcs will alongate along the insulator profile and may eventually cause the full insulator flashover [1].

A conducting layer is formed on the surface either by wetting the deposited pollution layer or deposition of conducting water, e.g. acid rain or salt water from the sea. LC flows through the conducting layer and heats to form a dry-band. The dry-band interrupts the LC and the voltage across the dry-band may be high enough to cause arcing. The partial arc may extend itself as the dry band is being elongated. To start a dry-band arcing, a dry band must first be formed. The formation of a dry band directly affects one of the important parameters, time-to-arcing. The formed dry band may affect the characteristic of the arcing that will be started subsequently, by affecting the type of arcing and duration of arcing [2].

The initiation of the dry-band is usually due to the non-uniform evaporation of wet layer. The evaporation is caused by the heat generated by the LC. By assuming that the convection is mainly responsible for initiation of dry band, established the condition of applied voltage for initiation of the dry bands [2].

Contamination-causing insulator flashover near coastal areas result in expensive power outages. The flashover mechanism is as follows ; dry contamination forms a more or less uniform layer on the insulator surface. The LC path is capacitive, the current magnitude is small and current shape is fairly sinusoidal with distortion. Moisture on insulator surface wets the contamination to produce a thin conductive layer. As wetting progresses, the LC path changes from capacitive to resistive, and simultaneously, current amplitude increases [3].

The phenomena leading to flashover of a polluted insulator are extremely complicated. Nevertheless, a highly simplified model can help to describe the most important processes. A LC flows which produces a linear potential distribution. This leads to a certain amount of drying of the contamination layer. A bridging of individual dry bands by means of partial arcs occurs which ultimately can turn into a complete flashover. This latter is prevented if complete drying of the surface occurs, when once more a linear potential distribution results but with current values much lower than the danger level. The entire mechanism can be regarded as a race between uniform drying and the cascading of partial arcs [4]. A basic idea shall be developed using a model conceived by F. Obenaus [4-5].

The observation of discharge, during its elongation, on an electrolyte filled channel modelling a polluted high voltage line

Manuscript received June 17th, 2009. This work was supported in part by the Scholarship of Postgraduate Education of Indonesia Government and National Institute of Technology.
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insulators shows that the latter emit, from its tip, some branches, which have a weaker luminous intensity. It was shown that flashover voltage increased asymptotically as the resistance per length of pollution rose. Otherwise, the flashover current would reduce as hyperbola as the resistance per length of pollution [6].

In general, flashover is defined as the dielectric breakdown of a gasous atmosphere or of vacuum in the neighborhood of an insulating surface. The discharge initiates and always develops in the gas because its dielectric strength is invariably inferior to that of a solid. Depending on gas pressure and electrical conductivity of the surface, the primary phenomena can be totally different, also the flashover progress mostly depends on the experimental conditions [7].

The objective of research is to investigate some comparisons between pattern of leakage current and discharge current phenomena on a porcelain insulator and a porcelain specimen respectively. To analyze these current patterns, it was used fast Fourier transform (FFT).

II. Experimental and Analysis Methods

The steps of research are described as follows. The first step on one hand was preparing porcelain specimen for discharge current measurement with artificial pollutant. On another one, it was prepared naturally coastal polluted porcelain insulator for leakage current measurement. This insulator has been polluted as long as eight month, installed at PLN switchyard of Pangandaran, West Java, just around 600 metres distance from the beach. As we know, a coastal area is one typical of pollution source [8-9].

Each equipment under test was tested in a hermetically sealed chamber, where temperature, humidity, pressure and applied voltage could be adjusted and measured simultaneously.

The size of the chamber was 120 cm x 120 cm x 150 cm (WxDxH). The measurements of leakage current and applied high voltage waveforms used a 100 MHz two-channel storage digital oscilloscope. The measured data could be recorded and transferred to a computer using USB (Universal Serial Bus) and could be saved in softcopy form. The data could be read and saved in Excel and Bitmap forms. The schematic diagram of experimental setup is shown on Figure 1.

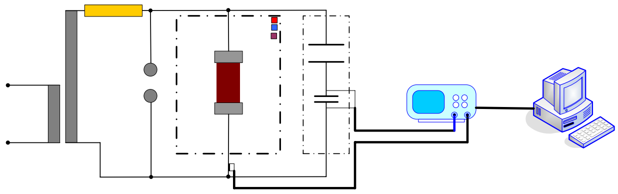


Fig. 1. Schematic diagram of experimental setup

Furthermore the data of current waveforms were analyzed using FFT. Thus, it was obtained harmonics on each current waveform. The total harmonic distortion (THD) is defined as the total ratio of harmonic components and the fundamental [10].

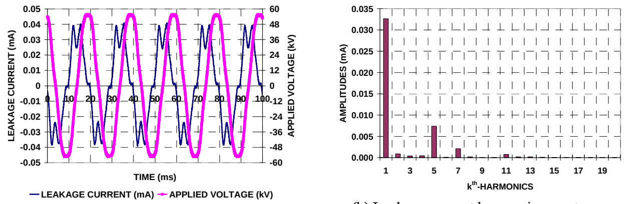
Thus, the frequency spectra were obtained on some conditions of experimental results. These implementations used the Danielson-Lanczos method [11].

In this research, the input parameters were maximum applied voltage, pressure, humidity and temperature. Otherwise, the output parameters were leakage or discharge current amplitude, first to twentieth odd and event harmonics of leakage and discharge current amplitudes, THD and phase angles in leading condition. Thus, it was obtained correlation(s) between input and output parameters.

III. Experimental Results and Discussion

A. Leakage Current

In dry hermetically sealed chamber condition, the waveform of typical leakage current measurement of porcelain insulator is shown on Figure 2. This waveform was obtained on condition of RH, temperature, pressure and maximum applied voltage were 71%, 42.4^{o}C, 0.2 kPa and 55.4 kV respectively. In dry condition, the pollutants stuck on porcelain insulator surface did not influence leakage current significantly. It is seen that the leakage current is far from sinusoidal waveform, and the phase angle is 74.9 degree, that is very high (Fig.2a). The second highest harmonics after fundamental is fifth harmonics, that is 17.94% to the amplitude of leakage current (Fig.2b).



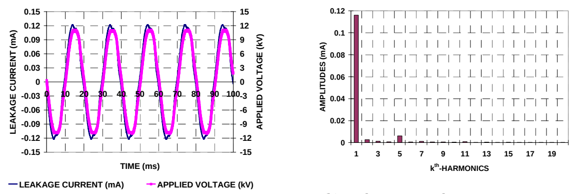
(a) Leakage current and applied voltage waveforms

(b) Leakage current harmonics spectrum

Fig. 2. The waveforms of dry polluted insulator

The third harmonic is very small, so that it still operates normally. Otherwise, THD is 23%. The harmonics appeared due to effect of mixed high capacitive-resistive properties generally. Thus, the harmonics would rise as the leading phase angle increased.

On other condition, Fig. 3a shows the leakage current and applied voltage waveforms on polluted insulator due to 99%, 26^{o}C, -0.8 kPa and 10.9 kV maximum applied voltage. In this condition, the phase difference between leakage current and applied voltage waves is 12.2 degree. This drastically reduces rather than that the dry one. Fig. 3b represents the frequency spectrum of leakage current waveform. It is seen that the second highest harmonics is also still fifth harmonics. Nevertheless, its percentage reduces to 5.1% compared to leakage current amplitude, and THD is only 6%, due to the leakage current waveform tends to relatively close pure sinusoidal wave. This is the most conductive condition among previous conditions, indicated by small total harmonic distortion.



(a) Leakage current and applied voltage waveforms

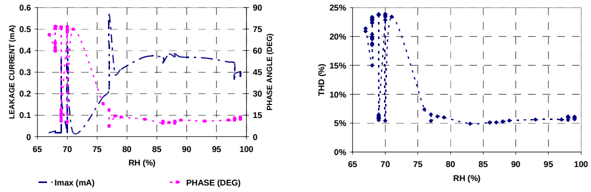
(b) Leakage current harmonics spectrum

Fig. 3. The waveforms of wet polluted insulator

This indicates that if the relative humidity increased, the percentage of fifth harmonics and THD would reduced, besides leakage current amplitude increased. The fifth harmonics and THD reduced to sign that the leakage current waveforms tent to be relatively more sinusoidal. However, the second highest magnitude is still fifth harmonics, after the fundamental.

International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:3, No:10, 2009

Figure 4a shows the leakage current (LC) amplitudes and phase angle as function of relative humidity (RH). Whereas, Figure 4b shows THD as function of relative humidity. Generally, it is seen that the leakage current amplitudes would increase as the relative humidity rose as rise parabola. Otherwise, the phase angle would reduce as the relative humidity rose as parabola. Whereas the THD reduced drastically as relative humidity increased. It is seen that such three quantities, leakage current amplitude, phase angle and THD, were significantly influenced by relative humidity. If it is watched closely too, other parameters, pressure and temperature, did not fairly affect to such three quantities. Nevertheless, the temperature reciprocally influenced the relative humidity.

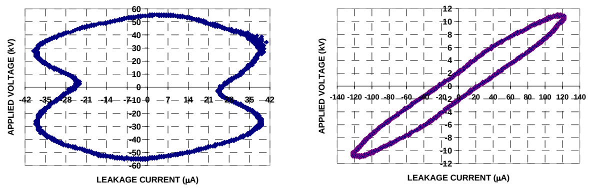


(a) LC amplitudes and phase angle as function of relative humidity

(b) THD as function of relative humidity

Fig. 4. LC, phase angle (a) and THD (b) as function of relative humidity

Figure 5a and 5b shows two typical different applied voltage magnitudes as function of yielded leakage current magnitude, for phase angle 74.9 and 12.2 degrees respectively. The phase angle was high, indicated by low humidity, meant the curve would be thick or fat, and vice versa, if the phase angle was low, signed by high humidity, meant the curve would be thin. Nevertheless, the relations between applied voltage and leakage current magnitudes were still linear. Thus, the property of insulator material was still linier too.



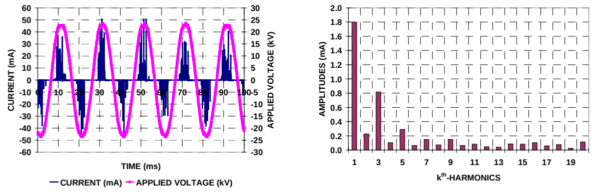
(a) Dry condition (71% RH), phase angle 74.9^o

(b) Wet condition (99% RH), phase angle 12.2^o

Fig. 5. Applied voltage magnitude as function of yielded LC magnitude for phase angle (a) 74.9^o and (b) 12.2^o

B. Discharge Current

Figure 6a shows discharge current and applied voltage waveforms of porcelain specimen, and corresponding frequency spectrum of discharge current is shown on Figure 6b. In this condition, the specimen was tested on -19 kPa, 23.52 kV$_{max}$, 25.4^{o}C, 66% of pressure, maximum amplitude applied voltage, temperature and relative humidity respectively. It is seen that the current wave amplitude bounce up and down drastically, usually, called intermittent. The uniqueness of frequency spectrum on this condition compared to the leakage current one is appearing of third harmonics dominantly, that is the highest among other harmonics, except the fundamental. It is also indicated by THD high, 53.8%.

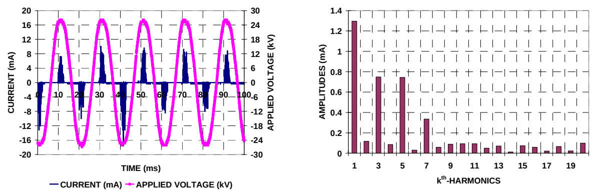


(a) Discharge current and applied voltage waveforms

(b) Discharge current harmonics spectrum

Fig. 6. The typical of (a) discharge current and (b) harmonics spectrum on low pressure

Otherwise, Figure 7a is discharge current and applied voltage waveforms of porcelain specimen on condition +19 kPa, 26.04 kV$_{max}$, 27.9^{o}C, 99% of pressure, applied voltage amplitude, temperature and relative humidity respectively, and corresponding frequency spectrum of discharge current on Figure 7b. In this condition, the current wave amplitude bounce up and down more infrequently or rarely, rather than previous one. It was occurred due to the pressure higher than the previous, so that the particles on the air tend to be more immune or insensitive to be experienced ionisation. The effect of pressure is also signed by harmonics spectrum or discharge current, that on high pressure there are other harmonics those are significant too, besides third harmonics after the fundamental. In this case, the other significant harmonics are fifth and seventh harmonics respectively.



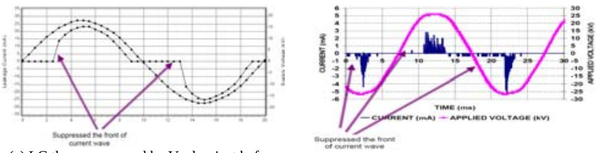
(a) Discharge current and applied voltage waveforms

(b) Discharge current harmonics spectrum

Fig. 7. The typical of (a) discharge current and (b) harmonics spectrum on high pressure

Nevertheless, the second highest harmonics of discharge current density after the fundamental is still third harmonics. However, in a low pressure, the percentage of third harmonics after the fundamental would be dominant among other harmonics. Of course, the discharge currents were not sinusoidal form, indicated beside by discharge current waveforms, also by the spectrum of harmonics or THD those very high, 90.8%.

Usually, the front of discharge current waves were suppressed tend fairly to the central waves. This means, that to be discharged it was necessary a threshold of voltage magnitude value. This phenomenon was occurred on both positive and negative magnitude values. However, after reach the peak of discharge current waves, the discharge current waveforms were suppressed more weakly that those on the fronts. These cases were suitable with the theory that proposed by Vosloo [8]. However, it was not occurred of discharge yet, still in leakage current condition. This theory proposed of waveform is shown by Figure 8(a). If this figure is compared to some figures experimental results of discharge current waveforms as above, or Figure 8(b), it is seen those above figures support or resemble the waveform theory proposed by Vosloo.

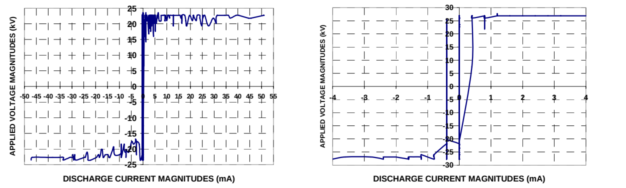


(a) LC theory proposed by Vosloo just before discharge occurred

(b) Author discharge current experimental result

Fig. 8. (a) LC theory proposed by **Vosloo** [8] just before discharge occurred and (b) discharge current experimental result

Figure 9 shows the applied voltage magnitude as function of yielded discharge current magnitude for pressure (a) -19 kPa as representation of low air pressure, and (b) +19 kPa as representation of high air pressure. It is shown these V-I characteristics are non-linear. It is indicated that Figure 9(a) is fairly more non-linear, bent up more sharply, and more be bounce up and down or more be oscillation rather than that Figure 9(b). It is reasonable V-I characteristics on Figure 10(a) was obtained on low pressure (-19 kPa). On low pressure, air particles on the specimen surface between high voltage electrodes would be more relatively susceptible to be ionised than that on high air pressure.



(a) Pressure -19 kPa

(b) Pressure +19 kPa

Fig. 9. Applied voltage magnitude as function of yielded discharge current magnitude for pressure (a) -19 kPa and (b) +19 kPa

Figure 10 shows the positive and negative peaks of discharge current as function of pressure that obtained by experimental results. Actually, the peaks of discharge current, whether positive or negative value, were occurred in intermittent. So that, in the experiments, the peak values were obtained randomly. The peaks of discharge current, besides depend upon pressure, it is also depend on applied voltage magnitudes, pollutants on the insulator specimen surfaces, leakage distance, form factor, environmental conditions and so on. Nevertheless, it is emphasized on the pressure effect. It is seen that the peaks of discharge current would decreased as pressure increased. The charts tend to be fairly hyperbola, with the empirical equations are shown on the figure.

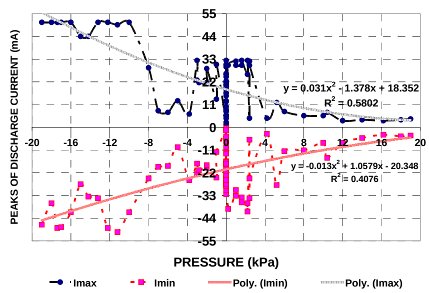
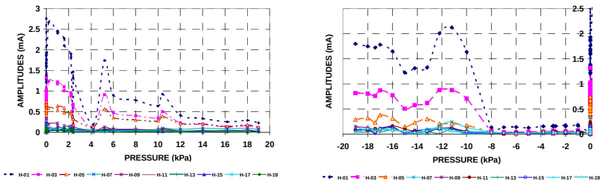


Fig. 10. Experimental results of (+) and (-) peaks of discharge current as function of pressure

Figure 11 shows the first to nineteenth odd harmonics amplitudes of discharge current as function of pressure, both for positive pressure (a) and for negative pressure (b). Positive pressure means the hermetically sealed chamber was compressed by compressor pump, and negative pressure means the hermetically sealed chamber was sucked by vacuum pump. Both figures indicate that the amplitudes of harmonics would reduce as the pressures increased. Both reducing phenomena are hyperbola. Nevertheless, the slopes are different, that on the negative pressure it is more drastic than that on the positive pressure. Furthermore, the amplitudes tend to be constant values. Usually, the values of amplitudes would be smaller for k^{th}-harmonics increased.

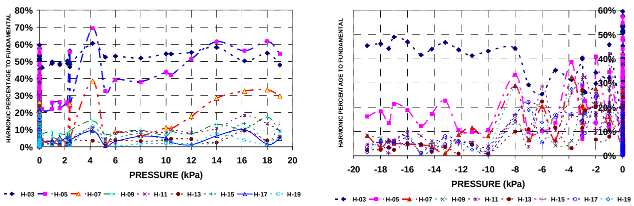


(a) Pressure above normal condition

(b) Pressure under normal condition

Fig. 11. Experimental results amplitudes of odd harmonics vs pressure on (a) (+) pressure and (b) (-) pressure

Otherwise, Figure 12 shows the percentage of third to nineteenth odd harmonics amplitudes to the corresponding fundamental amplitudes of discharge current as function of pressure both for positive pressure (a) and for negative pressure (b). The charts indicate those values tend to fairly increase. These mean the comparison of harmonic amplitude after fundamental to fundamental to fairly increase as pressure rise. Nevertheless, these increases are not as large as their amplitudes. This case was caused by the amplitudes of discharge currents, those also represented by the fundamental, would reduce significantly as the air pressure increased.

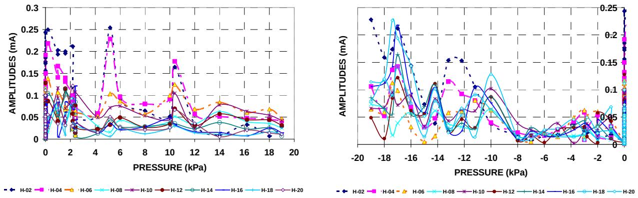


(a) Pressure above normal condition

(b) Pressure under normal condition

Fig. 12. Harmonic percentage to fundamental of odd harmonics vs pressure on (a) (+) pressure and (b) (-) pressure

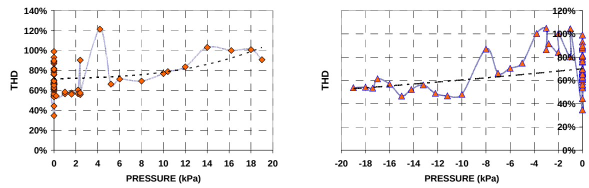
Figure 13 shows the second to twentieth even harmonics amplitudes of discharge current as function of pressure both for positive pressure (a) and for negative pressure (b). Both figures indicate that the amplitudes of harmonics would reduce as the pressures increased. Nevertheless, both their reducing or slope reducing and their amplitudes are generally smaller than those odd harmonics ones as shown on Figure 12. Close to high pressure values, the amplitude values of harmonics tend to reach a constant values. Usually, the values of amplitudes would be smaller for k^{th}-harmonics increased.



(a) Pressure above normal condition (b) Pressure under normal condition

Fig. 13. Experimental results amplitudes of even harmonics vs pressure on (a) (+) pressure and (b) (-) pressure

In general, the percentages of harmonic amplitudes after the fundamental to the corresponding fundamental are represented by THD. Figure 14 shows the values of THD as function of pressure on both positive (a) and negative (b) parts of pressures. Usually, the THD increases as the pressure rise. This means the amplitudes of harmonics after fundamental to corresponding fundamental amplitudes would rise if the pressure increased. This phenomenon was also caused dominantly by reducing discharge current amplitudes or fundamental harmonics due to air pressure increased, rather than increasing of remaining harmonic amplitudes.



(a) Pressure above normal condition (b) Pressure under normal condition

Fig. 14. THD vs pressure on (a) (+) and (b) (-) pressures

IV. Conclusion

According to experimental studies of LC and discharge current pattern measurements, it was obtained some points.

On high humidity polluted porcelain insulator, the LC tend to be fairly pure sinusoidal and coincide to applied voltage wave, and the insulator was highly conductive and resistive.

Otherwise, on low humidity porcelain insulator, the LC tend to be far away from sinusoidal, and the insulator was highly capacitive property.

Leakage currents had some properties, such as amplitudes were dominantly influenced by RH and pollutants, occurred in continue / stable, tend to be close to sinusoidal wave, THD is low, after the fundamental, the second highest is fifth harmonics, and the property is fairly linear.

Whereas discharge currents had some unique properties, i.e. Amplitudes were dominantly influenced by pressure, occurred in intermittent, tend to be far from sinusoidal wave, THD is high, tend to be experience a suppression on the front of wave, after the fundamental, the second highest is third harmonics and the property is extremely non-linear.

On a low pressure, the discharge current amplitudes, including its harmonics, especially third harmonics, would be high, and the current would be more intermittent. The lower the pressure, the more visible the third harmonics.

Acknowledgment

Authors herewith respectfully offer thanks to Higher Education Directorate of Indonesia Government for supporting this research and publication.

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