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# Study on Discharge Current Phenomena of Epoxy Resin Insulator Specimen

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***Abstract*—**This paper presents the experimental results of discharge current phenomena on various humidity, temperature, pressure and pollutant conditions of epoxy resin specimen. The leakage distance of specimen was 3 cm, that it was supplied by high voltage. The polluted condition was given with NaCl artificial pollutant. The conducted measurements were discharge current and applied voltage. The specimen was put in a hermetically sealed chamber, and the current waveforms were analyzed with FFT.

The result indicated that on discharge condition, the fifth harmonics still had dominant, rather than third one. The third harmonics tent to be appeared on low pressure heavily polluted condition, and followed by high humidity heavily polluted condition. On the heavily polluted specimen, the peaks discharge current points would be high and more frequent. Nevertheless, the specimen still had capacitive property. Besides that, usually discharge current points were more frequent. The influence of low pressure was still dominant to be easier to discharge. The non-linear property would be appear explicitly on low pressure and heavily polluted condition.

***Keywords*—**discharge current, third harmonic, fifth harmonic, epoxy resin, non-linear.

## I. Introduction

EPOXY RESIN is one of most important non-ceramic material of outdoor insulator, beside porcelain as ceramic material. Several flashovers are occurred on 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 energize insulator is covered with a conducting pollution layer, the 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].

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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 (leakage current) 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].

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. 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 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]. Flashover is defined as the dielectric breakdown of a gasous atmosphere or vacuum in the neighborhood of insulating surface. The discharge initiates and 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 discharge current phenomena on epoxy resin specimen. To analyze these current patterns, it was used FFT.

## II. Experimental and Analysis Methods

First step was preparing epoxy resin specimen as equipment under test, for discharge current measurement with artificial pollutant. This artificial pollutant was NaCl, as one typical of coastal polluted representation. As we know, a coastal area is one typical of pollution source [8-9].

The specimen was tested in a hermetically sealed chamber, where temperature, humidity, pressure and applied voltage could be adjusted and measured simultaneously.

The measurements of discharge current and applied voltage waveforms used a two-channel storage digital oscilloscope. The measured data could be recorded and transferred to a computer with USB and could be saved in softcopy form, read and saved in Excel. The schematic diagram of experimental setup is shown on Figure 1.

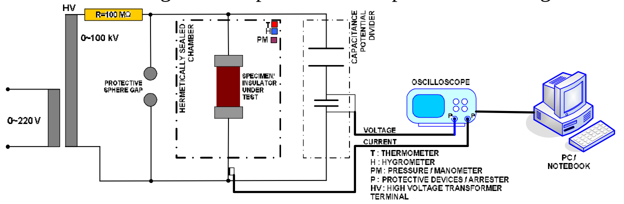



Fig. 1. Schematic diagram of experimental setup

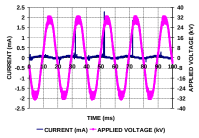
The data of current waveforms were analyzed with FFT. These implementations used the Danielson-Lanczos method [11]. Thus, it was obtained harmonics on each current waveform. The total harmonic distortion (THD) is defined as the total ratio of harmonic components and the fundamental [10].

## III. Experimental Results And Discussion

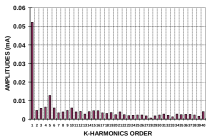
### A. Clean Specimen Condition

#### 1) Low RH specimen condition

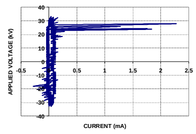
Figure 2 shows discharge current phenomenon of epoxy resin specimen on 23.9°C, 70%, 32.9 $kV_{max}$ of temperature, humidity and applied voltage amplitude respectively, and without pressure. This is sample of low RH typical condition. Figure 2(a) is discharge current and applied voltage waveforms on such condition. It is seen that the current would discharge suddenly when applied voltage wave closed to the peaks. It is stated that to reach a discharge, it was necessary a threshold. For this condition, the clean epoxy resin specimen still had capacitive property. Thus, the discharge condition did not change the epoxy resin specimen significantly. In other word, the clean epoxy resin specimen had capacitive property, although in a discharge condition. Figure 2(b) shows harmonics frequency spectrum of discharge current of Figure 2(a). Besides the fundamental frequency, the other harmonics were visible explicitly. Nevertheless, the second highest was still fifth harmonics. Figure 2(c) is the characteristics of applied voltage to discharge current. It is seen that the flash points were only few, however, their values were very high relatively.



(a) Current & voltage waveforms



(b) Current harmonics spectrum

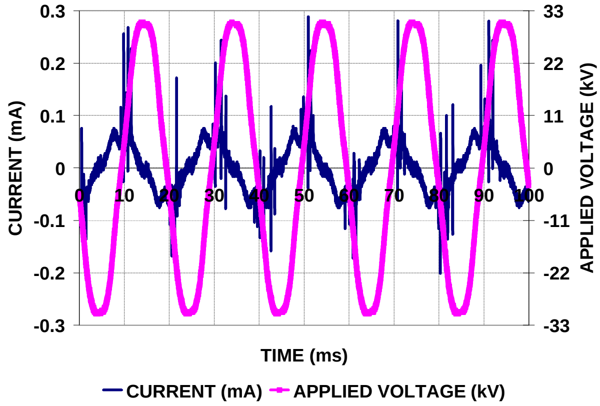


(c) Voltage-current characteristics

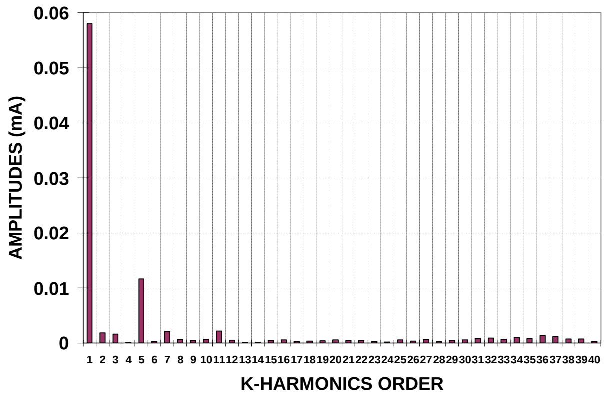
Fig. 2. Typical waveform of low RH clean specimen

#### 2) High RH specimen condition

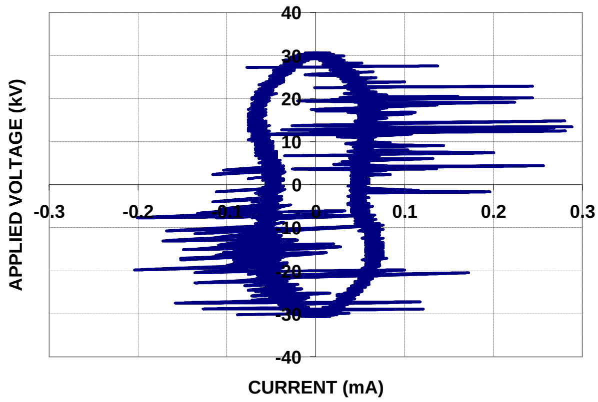
Figure 3 shows discharge current phenomenon of epoxy resin specimen on 26.4°C, 99%, 30.6 $kV_{max}$ of temperature, humidity and applied voltage amplitude respectively, and without pressure. This is sample of high relative humidity typical condition. Figure 3(a) is discharge current and applied voltage waveforms on such condition. It is seen that the intermittent discharge current was occurrence suddenly and significantly more rather than that on low humidity. It was easier to discharge on high humidity rather than on low humidity condition. Thus, the threshold voltage would be reduced. This case was caused by the existence of grains of water droplet on the surface of epoxy resin specimen. These water droplets raised quantity of discharges. However, the magnitudes of current discharge and applied voltage reduced explicitly. For this condition, the clean epoxy resin specimen still had capacitive property. Thus, the discharge condition did not change the epoxy resin specimen significantly. Figure 3(b) shows harmonics frequency spectrum of discharge current of Figure 3(a). Besides the fundamental frequency, the fifth harmonics was visible explicitly, as second highest of harmonics. Other harmonics were not visible significantly. Figure 3(c) is the characteristics of applied voltage to discharge current of high humidity clean epoxy resin specimen. It is seen that the flash points increased, compared to the flash points on low humidity. This case was caused by some water droplets on the specimen surface.




(a) Current & voltage waveforms




(b) Current harmonics spectrum




(c) Voltage-current characteristics

Fig. 3. Typical waveform of high RH clean specimen

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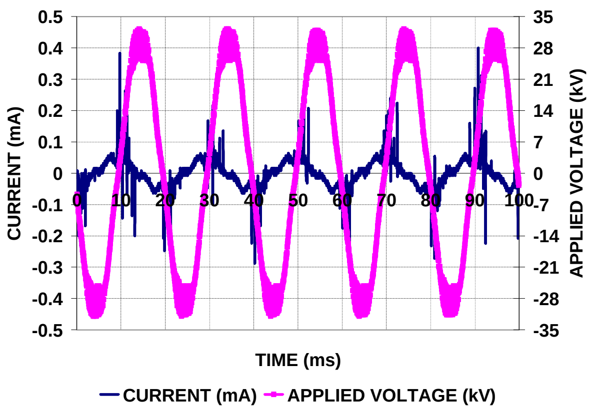
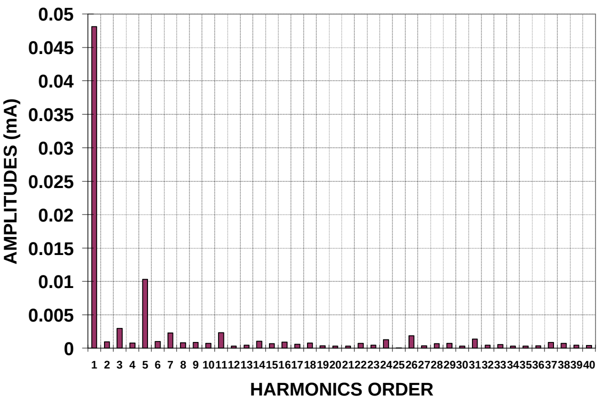
### 3) *Low Pressure specimen condition*

Figure 4 shows discharge current phenomenon of epoxy resin specimen on 26°C, 92%, -16 kPA and 30.6 $kV_{max}$ of temperature, humidity, pressure and applied voltage amplitude respectively. This is sample of low pressure typical condition. Figure 4(a) is discharge current and applied voltage waveforms on such condition. It is seen that the intermittent discharge current was occurrence suddenly and significantly more rather than that on low humidity. Nevertheless, the peaks of discharge current points were higher than that on high humidity. For this case of low pressure, the highest peak discharge current point was 0.4 mA, whereas for high humidity case, the highest peak discharge current point was 0.288 mA. Thus, the influence of low pressure was higher than the influence of high humidity. It is stated that it was easier to discharge on low pressure rather than on high humidity conditions. Thus, the threshold voltage would be reduced on low pressure. This case was caused supposedly by particle of air surrounding the specimen reduced, and furthermore, they were easier to discharge. Nevertheless, for this condition, the clean epoxy resin specimen still had capacitive property. It had capacitive property, although in a low pressure discharge condition.

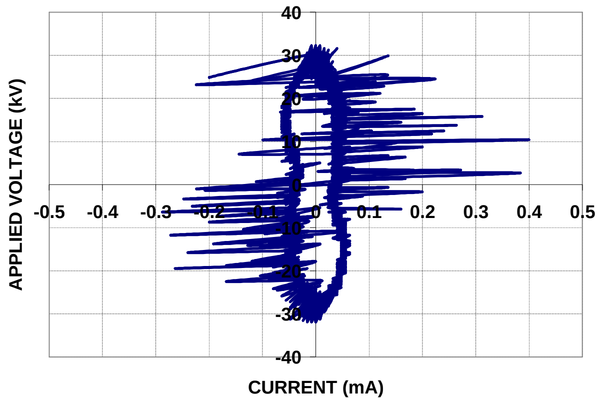
Figure 4(b) shows harmonics frequency spectrum of discharge current of Figure 4(a). Besides the fundamental frequency, the fifth harmonics was visible explicitly, as second highest of harmonics. Third harmonics was visible significantly enough, as third highest of harmonics. The lower of pressure, the more visible of third harmonics. Figure 4(c) is the characteristics of applied voltage to discharge current of low pressure clean epoxy resin specimen. It is seen that the flash points increased, compared to the flash points on low humidity or high humidity.




(a) Current & voltage waveforms




(b) Current harmonics spectrum



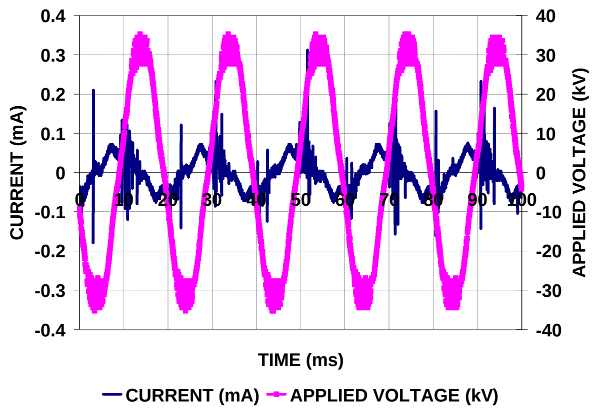

(c) Voltage-current characteristics

Fig. 4. Typical waveform of low pressure clean specimen

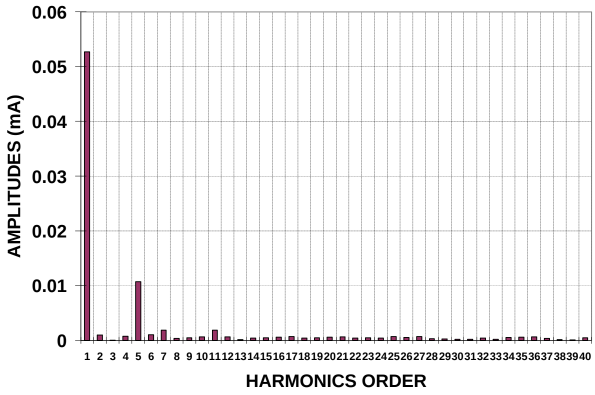
### 4) *High Pressure specimen condition*

Figure 5 shows discharge current phenomenon of epoxy resin specimen on 27.4°C, 99%, +17 kPA and 35.3 $kV_{max}$ of temperature, humidity, pressure and applied voltage amplitude respectively. This is sample of high pressure typical condition. Figure 5(a) is discharge current and applied voltage waveforms on such condition. It is seen that the intermittent discharge current was occurred significantly less than that on high pressure. Besides that, the applied voltage amplitude increased to reach a discharge condition. As sample of applied voltage amplitude, for this case, from 30.6 $kV_{max}$ on -16 kPa of pressure, became 35.3 $kV_{max}$ on +17 kPa of pressure. On other hand, the peak discharge point was lower, from 0.4 mA became 0.312 mA. It is stated that the increasing of pressure, it caused made higher of applied voltage amplitude to make discharge process, and on other word the current discharge point would reduce. It was more difficult to discharge on high pressure rather than that on low pressure. Thus, the threshold voltage would be increased on high pressure. This case was caused supposedly by particle of air surrounding the specimen increased, and furthermore, they were more difficult to discharge, due to be compressed. Nevertheless, for this condition, the clean epoxy resin specimen still had capacitive property.

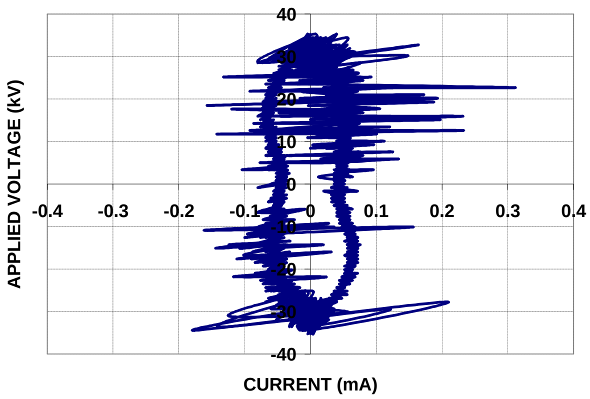
Figure 5(b) shows harmonics frequency spectrum of discharge current of Figure 5(a). Besides the fundamental frequency, the fifth harmonics was visible explicitly. Figure 5(c) is the characteristics of applied voltage to discharge current of high pressure clean epoxy resin specimen. It is seen that the flash points were less compared to that on low pressure.




(a) Current & voltage waveforms




(b) Current harmonics spectrum




(c) Voltage-current characteristics

Fig. 5. Typical waveform of high pressure clean specimen

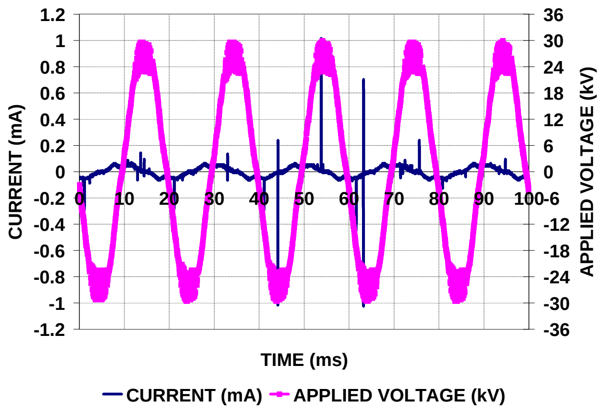
### *B. Lightly Artificial Contaminated Specimen*

For lightly artificial contamination sample, the epoxy resin specimen was immersed in NaCl solution of normal water, with conductivity of 12.96 mS (milliSiemens). After immersion, the specimen was dried, and then put inside the chamber.

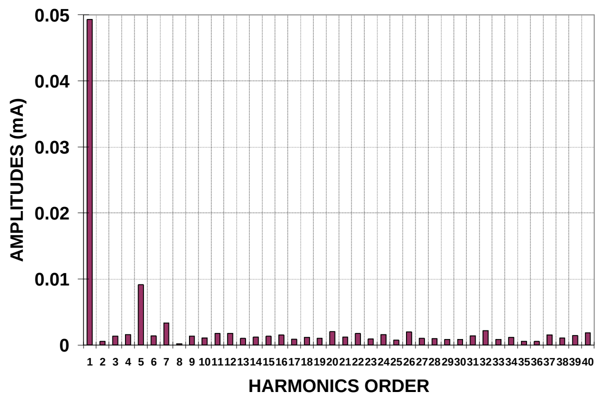
#### *1) Low Humidity specimen condition*

Figure 6 shows discharge current phenomenon of lightly artificial contaminated epoxy resin specimen on 26.3$^o$C, 68% and 35.3 kV$_{max}$ of temperature, humidity and applied voltage amplitude respectively, and without pressure. This is sample of low humidity typical condition. Figure 6(a) is discharge current and applied voltage waveforms on such condition. It is seen that the intermittent discharge current was occurred slightly to increase compared to that on low humidity of clean specimen. However, the peak discharge current significantly increased, for this applied voltage amplitude, it became +1.01 mA and -1.01 mA for positive and negative peaks. It is stated that the existence of contaminant, it caused made higher of peak discharge current, both for positive and negative values. It was easier to discharge due to existence of contaminant on the specimen. The threshold voltage would be reduced due to existence of contaminant. This case was caused by particle of contaminant on specimen surfaces. Nevertheless, for this condition, the clean epoxy resin specimen still had capacitive property.

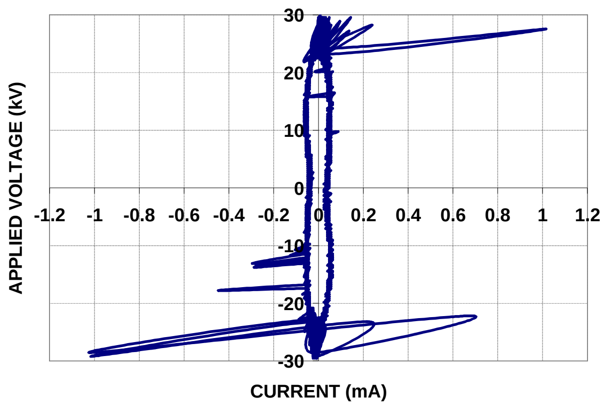
Figure 6(b) shows harmonics spectrum of discharge current of Figure 6(a). Besides the fundamental frequency, the fifth harmonics was visible explicitly, and other harmonics were also visible. However, they were far lower than third harmonics. Figure 6(c) is the characteristics of applied voltage to discharge current of low humidity for this specimen. It is seen that the flash points were same, but the peak discharge current values were higher compared to that low humidity clean specimen.




(a) Current & voltage waveforms




(b) Current harmonics spectrum



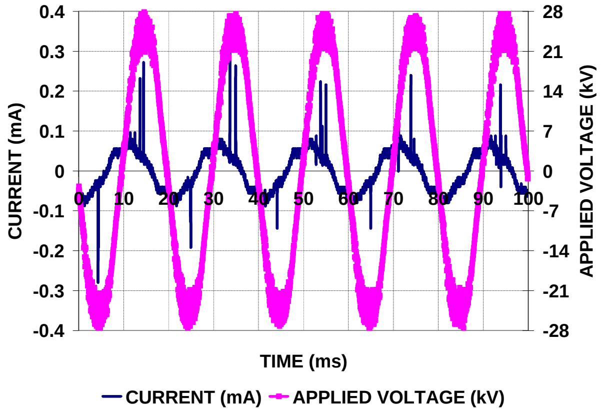

(c) Voltage-current characteristics

Fig. 6. Typical waveform of low RH lightly polluted specimen

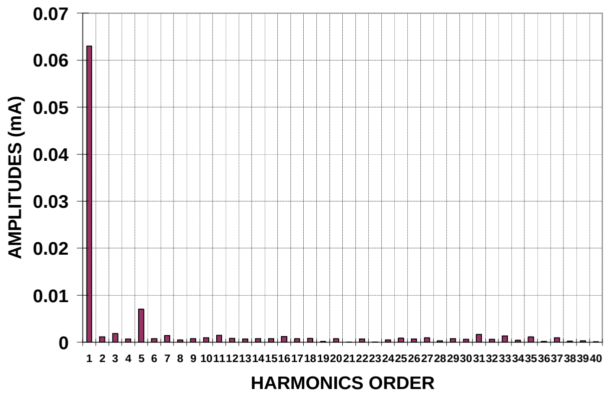
#### *2) High humidity specimen condition*

Figure 7 shows discharge current phenomenon of lightly artificial contaminated epoxy resin specimen on 26.3$^o$C, 99% and 27.9 kV$_{max}$ of temperature, humidity and applied voltage amplitude respectively, and without pressure. This is sample of high humidity typical condition. Figure 7(a) is discharge current and applied voltage waveforms on such condition. It is seen that the intermittent discharge current was occurred slightly to increase compared to that on low humidity of slightly contaminated specimen. However, the peak discharge current reduced, became 0.33 mA on this condition compared to previous 1.01 mA. This was also caused the applied voltage was lower than the previous on low humidity. Thus, it was easier to discharge due to high humidity. The threshold voltage would be reduced due to the grains of water droplets. This case was caused by particle of contaminant and water droplets on the specimen surfaces. Nevertheless, for this condition, the specimen still had capacitive property.

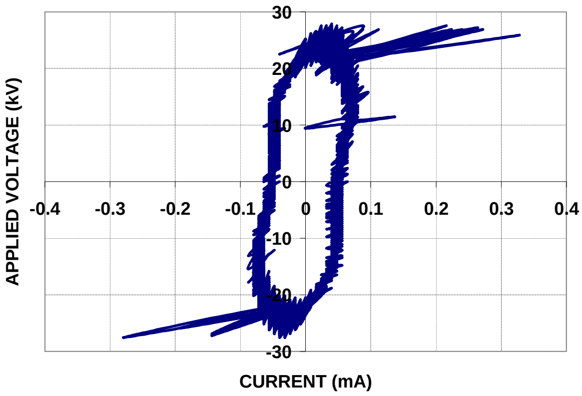
Figure 7(b) shows harmonics frequency spectrum of discharge current of Figure 7(a). Besides the fundamental frequency, the fifth harmonics was visible explicitly, and other harmonics were also visible slightly. However, they were far lower than third harmonics. Figure 7(c) is the characteristics of applied voltage to discharge current of high humidity for this specimen. It is seen that the flash points increased slightly, but the peak discharge current values were higher compared to that high humidity clean specimen.




(a) Current & voltage waveforms




(b) Current harmonics spectrum



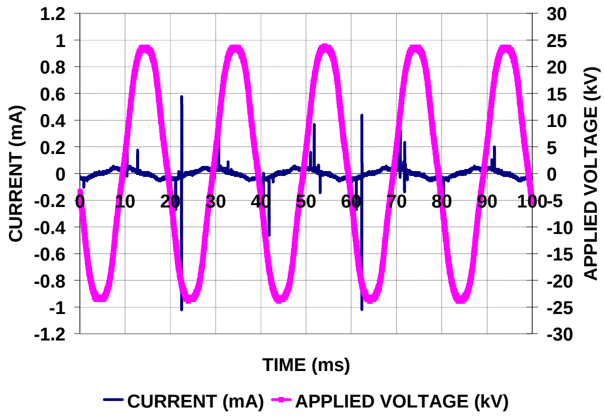

(c) Voltage-current characteristics

Fig. 7. Typical waveform of high RH lightly polluted specimen

### 3) *Low Pressure specimen condition*

Figure 8 shows discharge current phenomenon of epoxy resin specimen on 26.5$^{o}$C, 67%, -18.2 kPA and 34.8 kV$_{max}$ of temperature, humidity, pressure and applied voltage amplitude respectively. This is sample of low pressure typical condition. Figure 8(a) is discharge current and applied voltage waveforms on such condition. It is seen that the intermittent discharge current was occurrence suddenly and similar, but the peak discharge current points were lower than that on normal pressure. For this case of low pressure, the highest peak discharge current point was +0.374 mA and -1.01 mA. Thus, the influence of low pressure was significantly high. It was easier to discharge on low pressure rather than on high humidity conditions. Thus, the threshold voltage would be reduced on low pressure. This case was caused supposedly by particle of air surrounding the specimen reduced, and furthermore, they were easier to discharge. Nevertheless, for this condition, the lightly artificially contaminated epoxy resin specimen still had capacitive property. Thus, the discharge condition did not change the epoxy resin specimen significantly. It had capacitive property, although in a low pressure discharge condition.

Figure 8(b) shows harmonics frequency spectrum of discharge current of Figure 8(a). Besides the fundamental frequency, the fifth harmonics was visible explicitly, as second highest of harmonics. Other harmonics were visible slightly enough. Figure 8(c) is the characteristics of applied voltage to discharge current of low pressure lightly artificially contaminated epoxy resin specimen. It is seen that the flash points increased, compared to the flash points on low humidity lightly artificially contaminated specimen.




(a) Current & voltage waveforms

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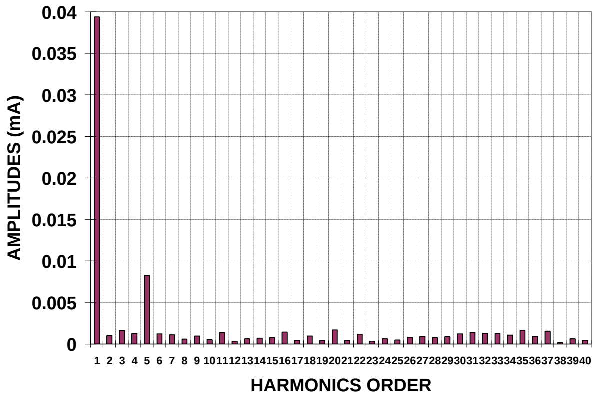
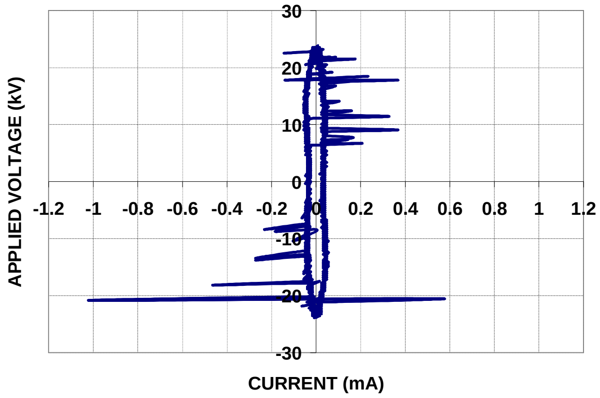



(b) Current harmonics spectrum



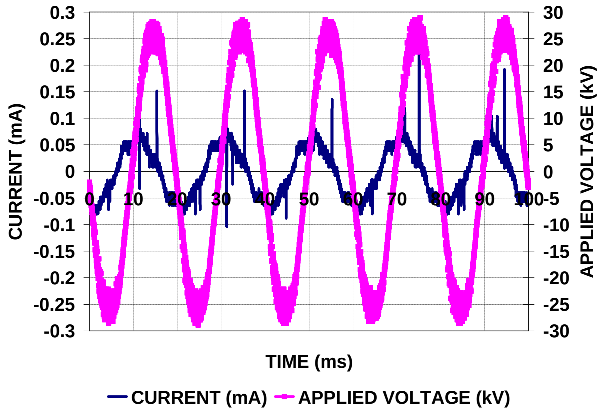

(c) Voltage-current characteristics

Fig. 8. Typical waveform of low pressure lightly polluted specimen

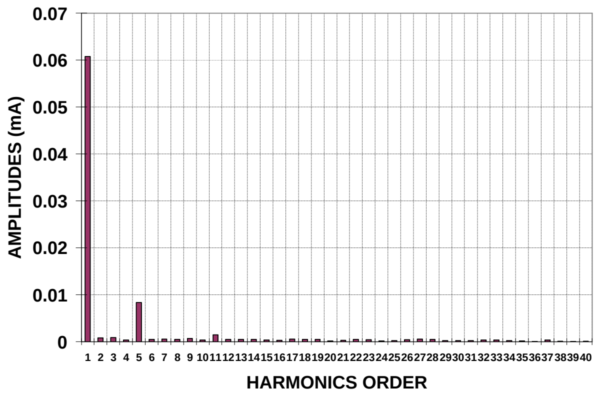
### *4) High Pressure specimen condition*

Figure 9 shows discharge current phenomenon of epoxy resin specimen on 27.5°C, 93%, +19.2 kPA and 28.2 $kV_{max}$ of temperature, humidity, pressure and applied voltage amplitude respectively. This is sample of high pressure typical condition. Figure 9(a) is discharge current and applied voltage waveforms on such condition. On this condition, the peak discharge current point was 0.27 mA. It was more difficult to discharge on high pressure rather than that on low pressure. This case was caused supposedly by particle of air surrounding the specimen increased, and furthermore, they were more difficult to discharge, due to be compressed. Nevertheless, for this condition, the specimen still had capacitive property.

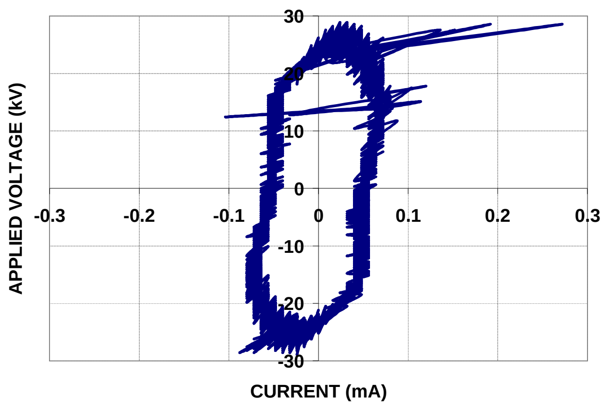
Figure 9(b) shows harmonics frequency spectrum of discharge current of Figure 9(a). Besides the fundamental frequency, the fifth harmonics was visible explicitly, and other harmonics were not visible. Figure 9(c) is the characteristics of applied voltage to discharge current of high pressure clean specimen.




(a) Current & voltage waveforms




(b) Current harmonics spectrum




(c) Voltage-current characteristics

Fig. 9. Typical waveform of high pressure lightly polluted specimen

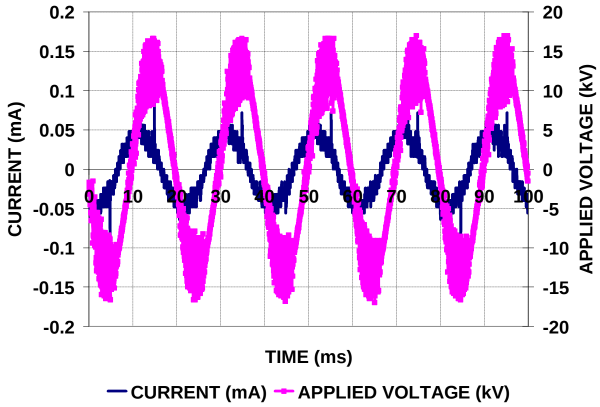
## *C. Heavy Artificially Contaminated Specimen*

For lightly artificial contamination sample, the epoxy resin specimen was immersed in NaCl solution of normal water, with conductivity of 17.09 mS (milliSiemens). After immersion, the specimen was dried, and then put inside the chamber.

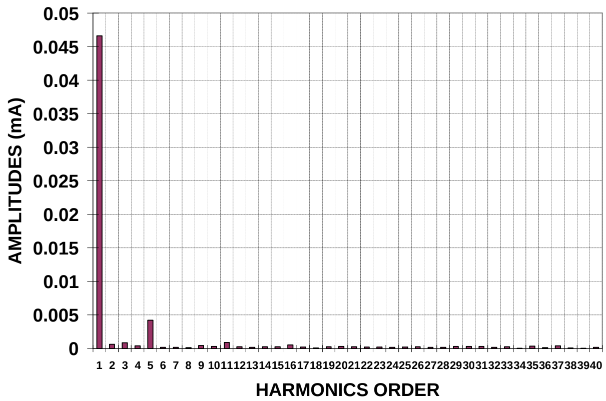
### *1) Low Humidity specimen condition*

Figure 10 shows discharge current phenomenon of heavily artificial contaminated epoxy resin specimen on 44.2°C, 69% and 16.6 $kV_{max}$ of temperature, humidity and applied voltage amplitude respectively, and without pressure. This is sample of low RH typical condition. Figure 10(a) is discharge current and applied voltage waveforms on such condition. It is seen that the intermittent discharge current was occurred slightly to increase compared to that on low humidity of clean specimen. It is stated that the existence of contaminant, it caused made higher of peak discharge current, both for positive and negative values. Although on this condition, the discharge current points were low, due to the applied voltage was also low. It was easier to discharge due to existence of contaminant on the specimen. Of course, the threshold voltage would be reduced due to existence of contaminant. This case was caused by particle of contaminant on specimen surfaces. Nevertheless, for this condition, the specimen still had capacitive property.

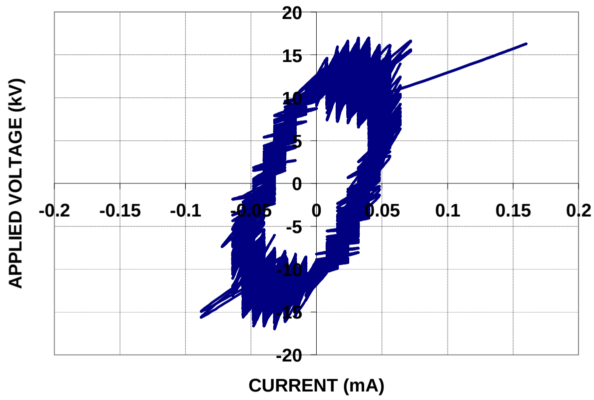
Figure 10(b) shows harmonics frequency spectrum of discharge current of Figure 10(a). Besides the fundamental frequency, the fifth harmonics was visible explicitly, but other harmonics were not visible significantly. However, they were far lower than fifth harmonics. The third harmonics was visible slightly. Figure 10(c) is the characteristics of applied voltage to discharge current of low humidity heavily artificial contaminated specimen. The peak discharge current values were lower due to the applied voltage was lower too.




(a) Current & voltage waveforms




(b) Current harmonics spectrum



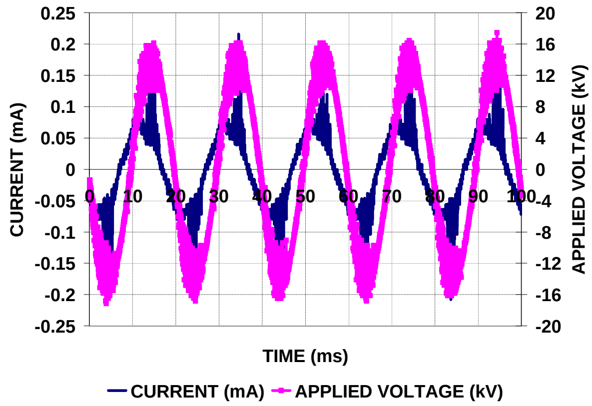

(c) Voltage-current characteristics

Fig. 10. Typical waveform of low RH heavily polluted specimen

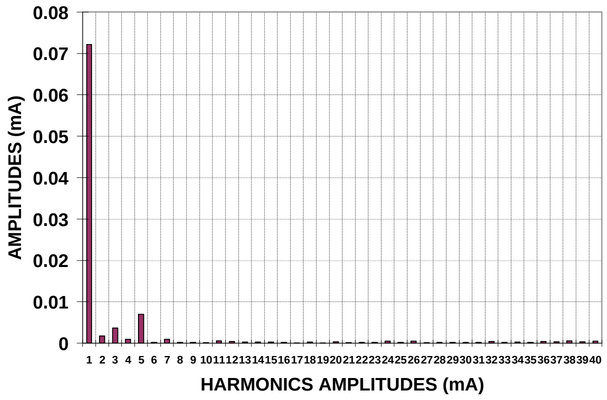
### 2) *High humidity specimen condition*

Figure 11 shows discharge current phenomenon of heavily artificial contaminated epoxy resin specimen on 30.2°C, 99% and 16.1 $kV_{max}$ of temperature, humidity and applied voltage amplitude respectively, and without pressure. This is sample of high humidity typical condition. Figure 11(a) is discharge current and applied voltage waveforms on such condition. It is seen that the intermittent discharge current was occurred significantly to increase compared to that on low humidity of slightly contaminated specimen. However, the peak discharge current increased, became 0.22 mA on this condition compared to that previous low humidity. This was also caused the applied voltage was lower than the previous on slightly contaminated specimen. Thus, it was easier to discharge due to high humidity. The threshold voltage would be reduced due to the grains of water droplets. This case was caused by particle of contaminant and water droplets on the specimen surfaces. Nevertheless, for this condition, the specimen still had capacitive property.

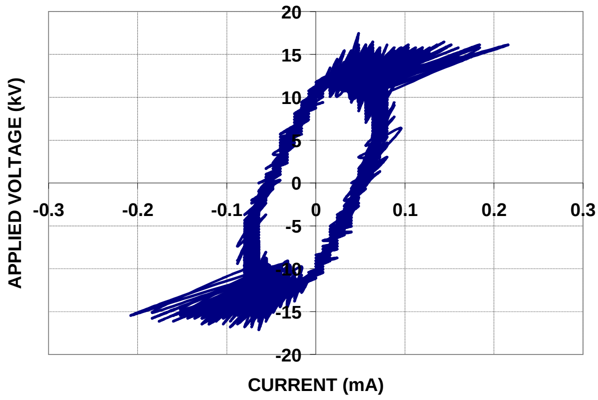
Figure 11(b) shows harmonics frequency spectrum of discharge current of Figure 11(a). Besides the fundamental frequency, the fifth harmonics was visible explicitly as second highest amplitude. Besides that, the third harmonics was also visible significantly, as third highest harmonics. Figure 11(c) is the characteristics of applied voltage to discharge current of high humidity heavily artificial contaminated epoxy resin specimen. It is seen that the flash points increased significantly.




(a) Current & voltage waveforms




(b) Current harmonics spectrum



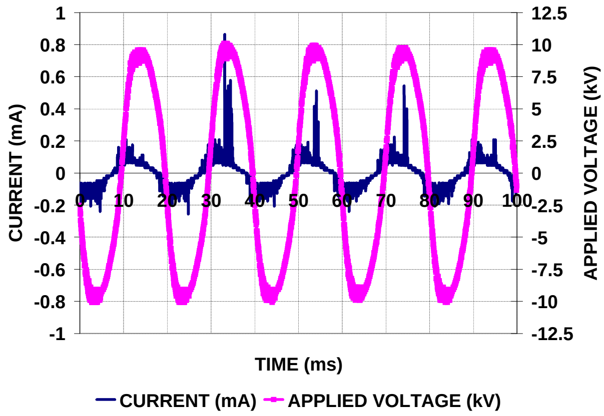

(c) Voltage-current characteristics

Fig. 11. Typical waveform of high RH heavily polluted specimen

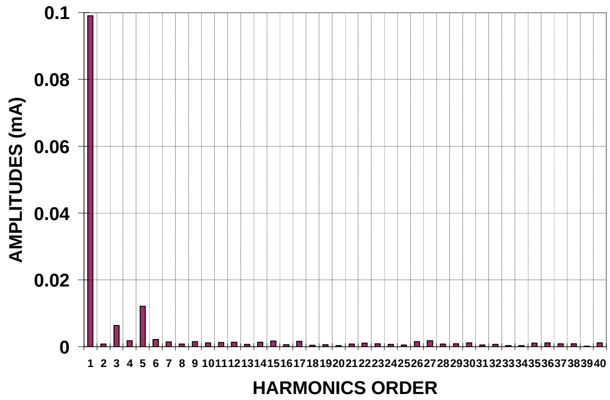
### 3) *Low Pressure specimen condition*

Figure 12 shows discharge current phenomenon of heavily artificial contaminated low pressure epoxy resin specimen on 26.1$^o$C, 88%, -19.8 kPA and 9.9 kV$_{max}$ of temperature, humidity, pressure and applied voltage amplitude respectively. This is sample of low pressure typical condition. Figure 12(a) is discharge current and applied voltage waveforms on such condition. It is seen that the intermittent discharge current was occurrence suddenly and more frequently than the previous. The peak discharge current points could reach 0.864 mA. Thus, the influence of low pressure was significantly high. It was easier to discharge on low pressure rather than on high humidity conditions. Thus, the threshold voltage would be reduced on low pressure. This case was caused supposedly by particle of air surrounding the specimen reduced, and furthermore, they were easier to discharge. Nevertheless, for this condition, the specimen still had capacitive property. Thus, the discharge condition did not change the epoxy resin specimen significantly. It had capacitive property, although in a low pressure discharge condition.

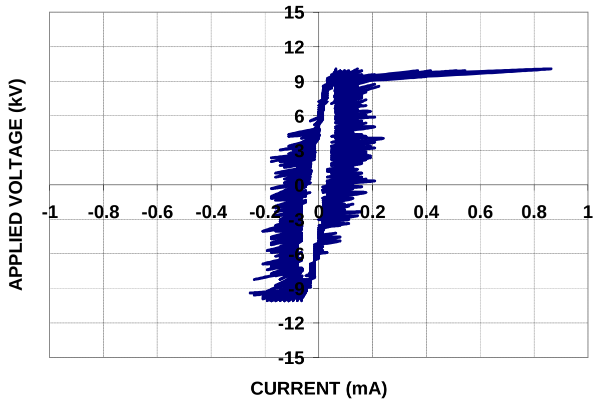
Figure 12(b) shows harmonics frequency spectrum of discharge current of Figure 12(a). Besides the fundamental frequency, the fifth harmonics was visible explicitly, as second highest of harmonics. The third harmonics was visible significantly enough. On this condition, the third harmonics was third highest amplitude, after fundamental and fifth harmonics. Figure 12(c) is the characteristics of applied voltage to discharge current of low pressure heavily artificial contaminated epoxy resin specimen. It is seen that the flash points and their amplitudes increased, compared to the flash points on low humidity of specimen.




(a) Current & voltage waveforms




(b) Current harmonics spectrum



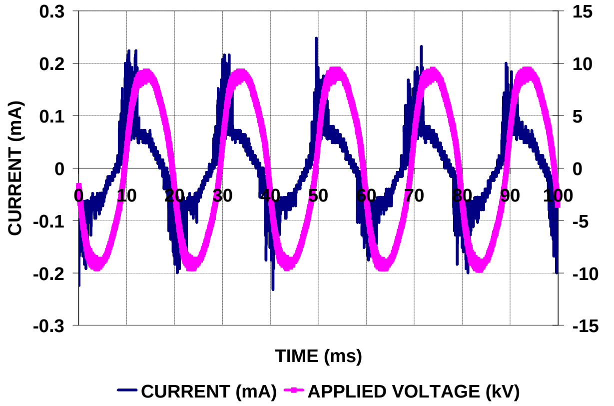

(c) Voltage-current characteristics

Fig. 12. Typical waveform of low pressure heavily polluted specimen

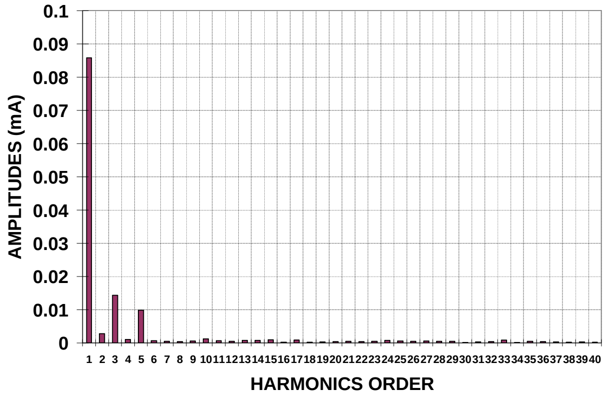
### 4) *High Pressure specimen condition*

Figure 13 shows discharge current phenomenon of epoxy resin specimen on 28.4$^o$C, 93%, +19 kPA and 9.4 kV$_{max}$ of temperature, humidity, pressure and applied voltage amplitude respectively. This is sample of high pressure typical condition. Figure 13(a) is discharge current and applied voltage waveforms on such condition. It is seen that the intermittent discharge current was occurred significantly less than that on high pressure. On this condition, the peak discharge current point was 0.248 mA. It was more difficult to discharge on high pressure rather than that on low pressure. This case was caused supposedly by particle of air surrounding the specimen increased, and furthermore, they were more difficult to discharge, due to be compressed. Nevertheless, for this condition, the specimen still had capacitive property.

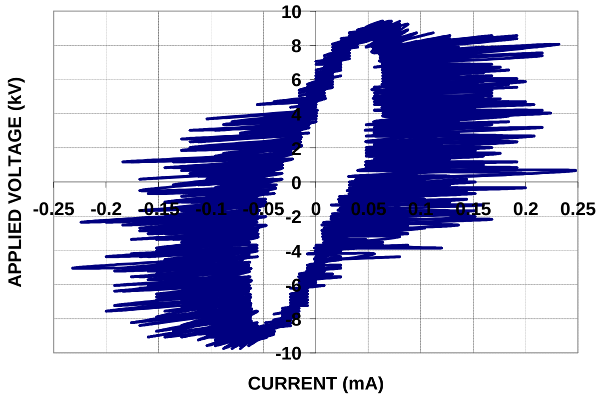
Figure 12(b) shows harmonics frequency spectrum of discharge current of Figure 12(a). Besides the fundamental frequency, the third harmonics was visible explicitly, and followed by fifth harmonics. This case is different from other spectra, that after fundamental frequency, the second highest amplitude was fifth harmonics. Figure 12(c) is the characteristics of applied voltage to discharge current of high pressure the specimen on this condition. It is seen that the flash points were more compared to the flash points on low pressure.




(a) Current & voltage waveforms




(b) Current harmonics spectrum




(c) Voltage-current characteristics

Fig. 13. Typical waveform of high pressure heavily polluted specimen

## IV. Conclusion

On discharge condition, the fifth harmonics still had dominant. The third harmonics tent to be appeared on low pressure heavily polluted condition, and followed by high humidity heavily polluted condition. On the heavily polluted specimen, the peaks discharge current points would be high and more frequent. Nevertheless, the specimen still had capacitive property. This phenomenon was different from the porcelain specimen, which it had resistive property. Usually discharge current points were more frequent. The influence of low pressure was still dominant, tend to be easier to discharge. The non-linear property would be appear explicitly on low pressure and heavily polluted condition.

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