Pulse-Sequence Analysis of Discharges in Air, Liquid and Solid Insulating Materials

Suwarno* and Teruyoshi. Mizutani**

Abstract – Electrical discharges may occur in gas, liquid as well as solid insulating materials. This paper describes the investigation results on the discharges in air, silicone oil and low density polyethylene (LDPE) using needle plane electrode system under AC voltage of 50 Hz. The experimental results showed that for discharge in air (corona), discharge pulses were concentrated around the peak of applied voltage at negative half cycle. For silicone oil positive as well as negative discharges were observed which concentrated around the peak of applied voltage. The positive pulse number was smaller but the magnitude was higher than that of negative discharge. Discharges in void took place at wider range of phase of applied voltage. The unbalance in pulse number and magnitude similar to that of oil discharges were observed. For electrical treeing in LDPE, the discharges were spread before the zero cross of the applied voltage up to the peak at both positive and negative half cycles. The discharge pulse sequence analysis indicated that the PD occurrence in air , oil and void were strongly affected by the magnitude of applied voltage. However, for electrical treeing it was observed that the discharge occurrence was strongly affected by the time derivative of the applied voltage (dv/dt).

Keywords: Air, Liquid, Solid, Discharge, Pulse-sequence, Analysis

1. Introduction

Insulation is an important part of a high voltage apparatus. The insulation has to be able to withstand the operational electric field in order to make the apparatus working well. Due to high voltage and several extreme conditions, discharges may take place in the insulation. In air corona discharge is commonly observed[1]. In liquid insulating materials discharge due to streamer were reported[2,3]. In solid insulating materials, discharges associated with void and electrical treeing are often observed[4,5,6].

The occurrence of discharges in an insulating material usually related with aging of the insulation and precursor of the failure of the insulation[7,8]. Therefore, understanding of the discharge is very important to know the condition of the insulation. This become more important since recently a condition- based maintenance (CBM) was introduced to power system. The maintenance system requires the information on the condition of the apparatuses including the insulation system. By using the particular characteristics of the discharges and its patterns, the discharge sources may be recognized and the insulation condition may be assessed.

* Dept. of Electrical Engineering, Bandung Institute of Technology Bandung, Indonesia.(suwarno@ieee.org)
** Dept. of Electrical Engineering, Nagoya University, Japan
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This paper reports the investigation results on the phase-resolved measurement and pulse-sequence analysis of discharges took place in air, silicone oil and low density polyethylene. The three insulating materials are widely used in high voltage apparatuses. Phase-resolved and PD pulse-sequence analysis were used to interpret the mechanism of the PD and to clarify the physical phenomenon behind the occurrence of the PD.

2. Experiment

2.1 Sample and electrode system

Samples used in the experiment are air, silicone oil and low density polyethylene. A needle -plane electrode system as shown in Fig. 1 was used. The needle electrode (Ogura Jewellery) has radius of tip of 3 μm and the curvature of 30°. The medium between the needle and plane electrode was air for corona experiment. For investigating the discharge in liquid insulating material, silicone oil with viscosity of 500 cs was used and was put between the electrodes. PD in solid insulating material was investigated in LDPE samples. There are two kinds of LDPE samples. First sample is a sample with 1 mm length of void at the tip of needle electrode and second sample without void at the tip of the needle electrode. An AC voltage was applied to the needle electrode.

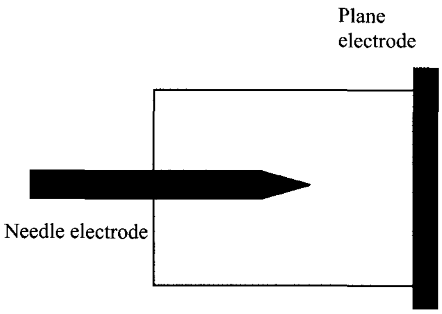


Fig. 1. Sample – electrode arrangement

2.2 Measurement system

Discharges occurred in the insulating materials were measured using a PC based measurement system as shown in Fig. 2. The discharges occurred in the sample were detected with an RC detector with R of 2 kΩ and C of 330 pF with a lower cut off frequency of 250 kHz. The system is able to measure and to show PD pulses in the θ-q-n windows. Here θ is the phase of PD occurrence, q is the magnitude of discharge and n is the PD number. During measurement discharges were detected by a discharge detector. The detector is a kind of integrator. The output of the detector is proportional to the charge of the discharge. The output of the detector was measured by PD analyser and digitized. The digital data was transferred to a PC for further analysis. Calibration of the measurement system is done by applying a known PD pulses from a PD calibrator at sample and the system is run to measure. The sensitivity of the measurement system was obtained from the pC of the calibrated PD pulses and the measured voltage indicated in the computer. The typical sensitivity of 55 pC/V was used in the experiment. Using the measuring system the discharge magnitude, frequency as well as the phase of discharge occurrence in the applied voltage cycles is measured and the digital data are storage in the PC. Further analysis of the discharges was done by using the PC.

3. Experimental Results

3.1 Discharge in air

Fig. 3a shows θ–q-n pattern of discharges in air (corona) at the tip of the needle electrode at applied voltage of 3 kV. The horizontal axis is the phase of the applied voltage (degree) while the vertical axis is the magnitude of the discharge in pC. Each point represents a discharge pulse. The coordinate of each point indicates the magnitude of the discharge and the phase where the discharge took place. The Fig. was obtained from discharge pulses took place in 10 consecutive cycles.

From the Fig. it is seen that there are only negative discharges observed in associated with corona. This indicated that negative discharges much more easily to occur in the corona. The phenomenon related with the electrode arrangement. Negative discharge took place when the needle electrode was negative. The fact revealed that the initial electron was released from the needle tip. The Fig. also showed that almost PD were concentrated around the peak of the applied voltage suggested that the magnitude of the applied voltage determined the occurrence of the discharges.

Fig. 3b. shows the discharge pulse train took place in a half cycle. The PD pulse number is about 25 pulses per cycle. The time between 2 discharge was very small and the discharge almost coincide each other. This results indicated that discharges took place at a small over voltage around the peak of the applied voltage.

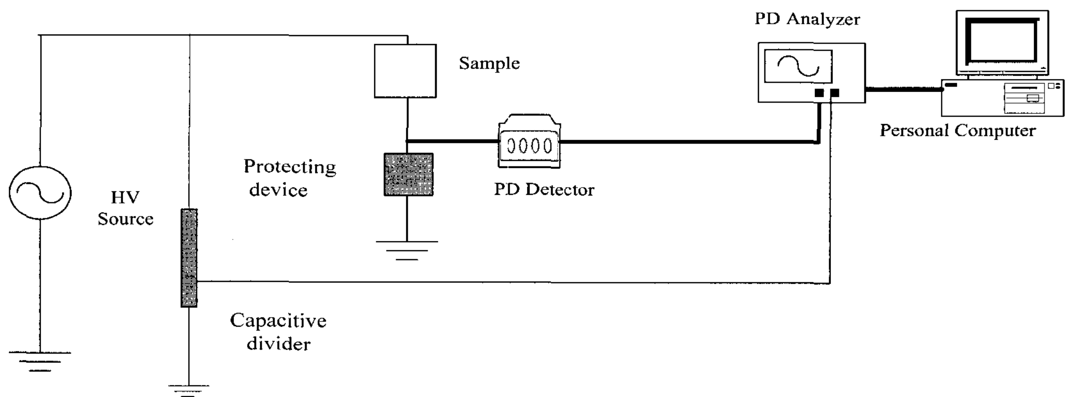


Fig. 2. PC-based PD measurement system

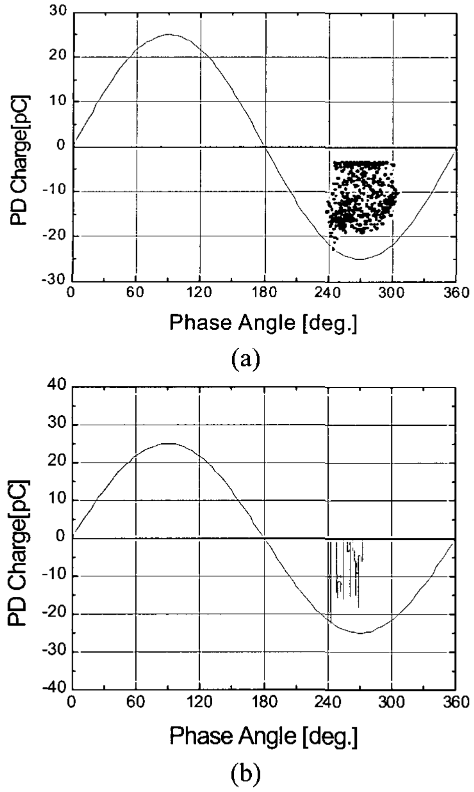


Fig. 3. Typical θ-q-n patterns (a) and pulse sequence (b) of discharges due to corona in air (8 mm electrode separation and 3 kV applied voltage)

3.2 Discharge in silicone oil

Fig. 4 shows θ–q-n pattern and pulse sequence of discharges in silicone oil at 4 mm electrode separation and 9 kV applied voltage. The Fig. was obtained from discharge pulses took place in 10 consecutive cycles. From Fig. 4.a it is seen that positive and negative discharges observed in silicone oil. This indicates that initial electrons are available in both polarity of the needle and silicone molecules played important role in releasing the initial electrons. The Fig. also indicates that the magnitude of positive discharge was higher than negative discharge. This means that positive discharges took place in higher over voltage than negative one. This may be due to the availability of initial electron for positive discharges was more difficult to occur than for negative discharges.

This asymmetrical behavior reflects the asymmetrical role of electrode system in producing discharge in silicone oil. Similar behavior was also observed in transformer oil and perflouropolyether[9]. The magnitude of discharge in both half cycles was proportional to the applied voltage.

Fig. 4.b shows discharge pulse train took place in a half cycle. From the Fig. it is seen that discharge occurrence was distributed around the peak of the applied voltage both positive and negative half cycles. The typical PD numbers were 8 and 12 for positive and negative half cycles respectively. The time between 2 discharges in positive half cycle was around 500 μs which is higher than 280 μs for negative discharges.

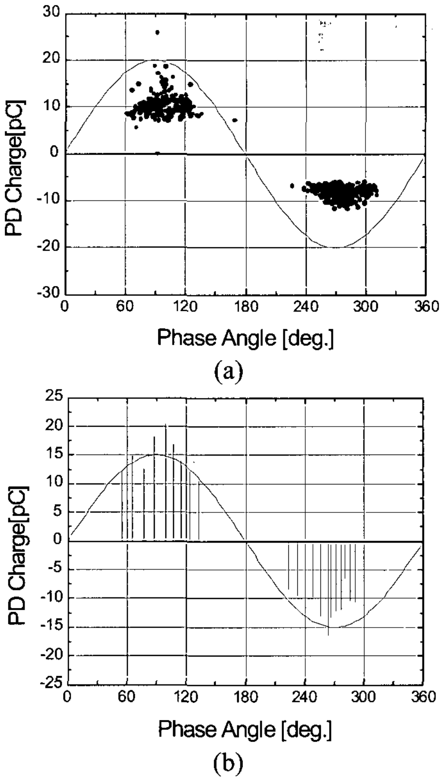
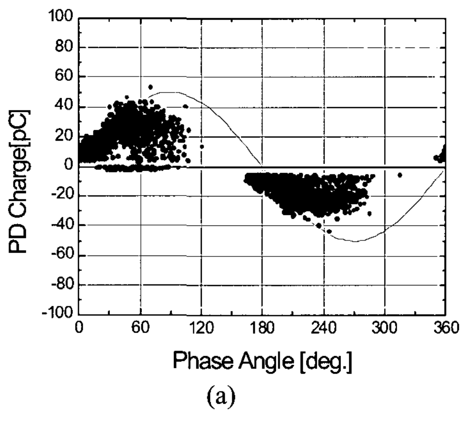


Fig. 4. Typical θ-q-n patterns (a) and pulse sequence (b) of discharges in silicone oil with 4 mm electrode separation at 9 kV applied voltage

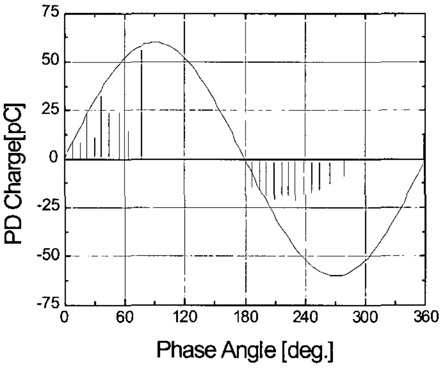
The PD pulse sequence as shown in fig 3b. also showed that the PD magnitude in silicone oil was greatly affected by the instantaneous applied voltage.

3.3 Discharge in a void in LDPE

Fig. 5.a shows the typical PD pattern of a 1 mm void in LDPE with 8 mm electrode separation at applied voltage of 4.5 kV .



(a)



(b)

Fig. 5. Typical θ-q-n patterns (a) and pulse sequence (b) of discharges in a void in LDPE

As can be seen from the Fig., the PD magnitude of PD pulses occurred at positive half cycle was slightly higher than that of negative. This indicated that in the case of void PD, positive PD was slightly more difficult to occur than that of negative PD. This was attributed to the initial charge for PD initiation. Higher energy was required for initial charge from the polymer side (positive polarity) than that from needle tip (negative polarity). This phenomenon was similar to discharge in silicone oil. The Fig. also showed that there are positive discharges took place at negative applied voltage (350^o – 360^o) and negative discharge occurred at positive applied voltage (170^o – 180^o). The phase shift is due to the effect of space charge in the polyethylene caused by the discharge the proceeding half cycle which increased the surface conductivity [10] and made phase shift of actual void voltage from that of external applied voltage.

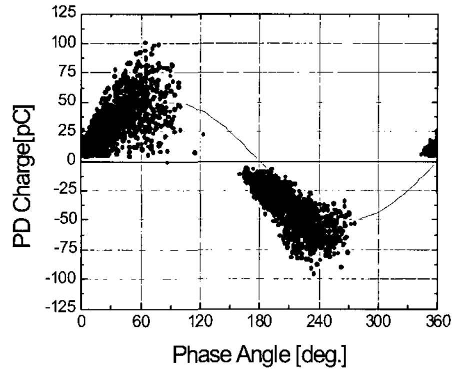
Fig. 5b. shows the PD trains in a cycle. As indicated in the Fig., the positive PD magnitude was slightly higher than that of negative one. The time between two consecutive PD pulses was around 0.4 ms.

3.4 Discharge due to electrical treeing in LDPE

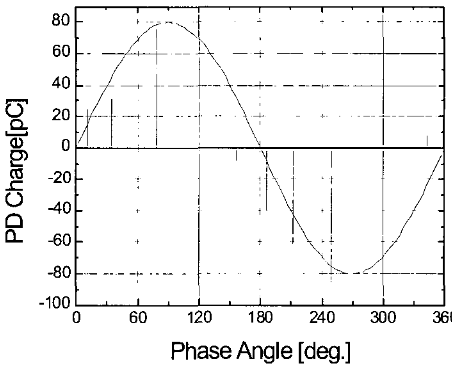
Fig. 6 shows θ–q-n pattern and pulse sequence of discharges due to electrical treeing in LDPE. The distance between the needle tip and plane electrode was 8 mm and the applied voltage was 8 kV for 100 minutes.

The tree length was around 800 μm. The Fig. was obtained from discharge pulses took place in 50 consecutive cycles. From Fig. 6.a it is seen that positive and negative discharges observed in the treeing. The Fig. also indicates that the magnitude of positive discharge was slightly higher than negative discharge. This means that positive discharges took place in higher over voltage and the availability of initial electron for positive discharge was more difficult than for negative discharge.

The Fig. also indicates that the magnitude of the discharge increased with instantaneous voltage. The discharge took place around the zero cross of the applied voltage and distributed up to the peak. Similar to that of void discharges, phase shift was also observed in the electrical treeing discharges.



(a)



(b)

Fig. 6. Typical θ-q-n patterns (a) and pulse sequence (b) of discharges due to electrical treeing in LDPE with 8 mm electrode separation and 8 kV applied voltage

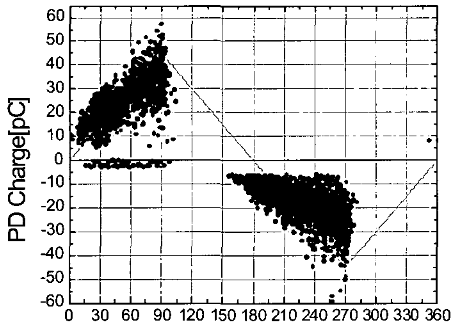
Fig. 6.b shows pulse sequence of discharges took place in positive and negative half cycles. From the Fig. it is clearly seen that discharge occurrence (repetition rate) was higher at around zero cross of applied voltage (high the dv/dt) than that around peak (small dv/dt) of the applied voltage. These suggested the important role of the time derivative of applied voltage (dv/dt) on the occurrence of treeing discharges. The time between 2 discharges around zero cross was around 1000 μs and around 1400 μs for discharges took place around peak

The number of discharge pulses in each half cycle was small (around 4). This Fig. was much smaller than that of discharge due to corona and discharge in silicone oil.

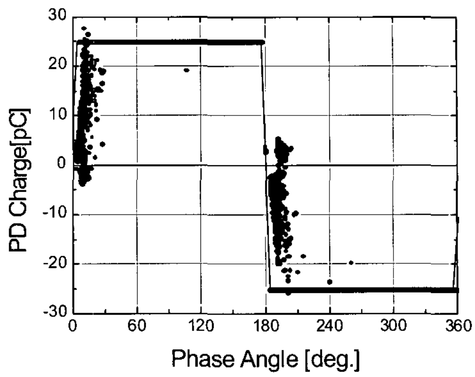
The role of instantaneous applied voltage (v(t)) in determining the magnitude of the discharges and the role of the time derivative of the applied voltage (dv/dt) in determining the occurrence of the discharges due to electrical treeing are much clarified by the θ-q-n pattern under triangular and rectangular applied voltages as shown in Fig. 7.

As shown in fig 7.a, under triangular applied voltage the pattern was triangular indicating the role of applied voltage in determining the discharge magnitude [11].

Fig. 7.b. shows the θ-q-n pattern of discharge due to electrical treeing under rectangular voltage. The magnitude of the discharges reflected well the shape of the rectangular applied voltage. The discharges only took place around zero cross where dv/dt was not zero and high enough to initiate the discharge. This clarified the role of dv/dt in determining the probability of discharge occurrence[5].



(a)



(b)

Fig. 7. Typical θ-q-n pattern due to electrical treeing under triangular voltage (a) and rectangular voltage (b) with 8 mm electrode separation at 9 kV (triangular) and 6 kV (rectangular)

From the experimental results, the characteristics of the discharges in air, liquid and solid insulating materials can be summarized as indicated in table 1.

Table 1. Summary of the characteristics of discharges in air, silicone oil and LDPE

	Corona	PD in Silicone Oil	Void PD	Treeing PD
Phase of PD Occurrence and possible factors affected the PD occurrence	Almost at around peak of negative half cycle of applied voltage suggesting the instantaneous voltage role on the PD occurrence	At around peak of applied voltage suggesting the instantaneous voltage role on the PD occurrence	Starting from about 45° before zero cross up to peak of applied voltage. Both instantaneous voltage and time derivative of applied voltage affect the PD occurrence.	Distributed from several deg. Before zero cross up to peak of applied voltage. Time derivative of applied voltage (dv/dt)determines the PD occurrence.
PD Magnitude	Depend on the instantaneous voltage. Almost constant patterns reflected fast recovery of the dielectric.	Depend on the instantaneous voltage. Almost constant patterns reflected the recovery of the dielectric.	Depends on the time derivative of the applied voltage.	Depend on the instantaneous voltage
PD Unbalance	PD only observed at negative half cycle	PD at both polarities. Positive PD magnitude was bigger than negative but PD number was smaller	PD at both polarities. Positive PD magnitude was bigger than negative but PD number was smaller.	PD at both polarities. Positive PD magnitude was bigger than negative but PD number was smaller
Pulse Sequence	Many PD pulses at negative half cycle and concentrated around 90 deg	Many PD pulses and distributed around peak of applied voltage of both polarities. No phase shift was observed.	Many PD pulses at each half cycles and distributed over a large phase angle. Phase shift was observed which reflected the effect of space charge.	A few PD pulses in each half cycles. Phase shift was observed which reflected strong effect of space charge.

4. Conclusion

Based on the experimental results some conclusions can be drawn as follows: There are differences in characteristics among discharges in air, silicone oil and LDPE. The differences related with the magnitude and the phase or discharge occurrences. The magnitude as well as discharge occurrences in air and silicone oil are greatly dependent on the instantaneous applied voltage. In LDPE, the magnitude and PD occurrence are dependent of instantaneous applied voltage while for electrical treeing the discharge magnitude is greatly affected by the applied voltage but the discharge occurrence is dependent on the time derivative of the applied voltage. The discharge characteristics and patterns are important to discriminate the origin of discharge sources

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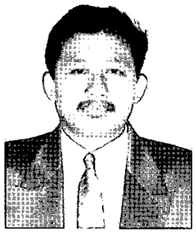

Suwarno

Dr. Suwarno was born in Indonesia in 1965. He received BSc and MSc from The Department of Electrical Engineering, Bandung Institute of Technology. Bandung, Indonesia in 1988 and 1991 respectively. He received PhD from Nagoya University, Japan in 1996 in the field of High Voltage Electrical Insulation. Dr. Suwarno is an associate professor in The Department of Electrical Engineering, Bandung Institute of Technology. His research interests are High Voltage Insulating Materials and Technology, Electro-magnetic Compatibility and High Voltage Industrial Application. Dr. Suwarno is recipient of The Best Paper Award from IEEE Queensland (ICPADM 1994), Excellent Paper Awards from IEE Japan 1994 and 1995 and Best Paper Presentation from ACED (Seoul 2003). Dr. Suwarno is a member of International Advisory Committee of ICPADM, ISEIM and a member of International Technical Committee of ISH 2007 and The General Chairman of ICPADM 2006. Dr. Suwarno is a member IEEE.

Teruyoshi. Mizutani

Dr. Teruyoshi Mizutani was born on May 9th ,1941. He received bachelor, master and doctor degree from Nagoya University in 1964, 1966 and 1970 respectively. He was Professor at Dept. of Electrical Engineering & Computer Science, Nagoya University. Since 2005 he is professor emeritus Nagoya University, Professor of. Aichi Institute of Technology, Japan and President of Japan Electric Cable Technology Center. His research interest are Conduction, Breakdown and Aging Phenomena in Insulating Materials, Aging and Residual Life of Insulating Materials and Power Apparatus and Computer-Aided Diagnostic Systems for Power Apparatus and System, Organic EL Devices and Their Applications, Organic Optical/Electronic Devices (Organic Electronics), Amorphous Si, SiC and C Films for Solar Cell. Prof. Mizutani has published more than 290 journal papers and 300 international conference papers. He is also author or co-author of more than 10 books. Prof. Mizutani is member of IEE Japan, and IEEE Fellow. He received IEEE Fellow Award (1995), IEEE 3rd Millennium Medal Award (2000) ,IEEJ Award for Outstanding Contributions (1997), IEEJ Best Paper Awards (1977, 1995 & 2002), and SMERJ Best Paper Award (1992)