DETECTION OF PARTIAL DISCHARGE AND ELECTRICAL TREE DEVELOPMENT IN SOLID DIELECTRIC INSULATORS BY RADIATED ELECTRO-MAGNETIC WAVES

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Abstract: We have successfully demonstrated that partial discharges in solid dielectric insulators can be distinguishable by using specific frequency of detected electromagnetic wave. And the higher frequency components are associated with the progress of electrical tree and degradation of dielectric insulation. By focusing the above-mentioned specific electro-magnetic frequencies and their signal levels, especially at higher frequency components, it is useful for detection of partial discharge and insulating assessment for power equipments, cables and their accessories consisting of solid insulation media such as epoxy resin and polyethylene.

1 INTRODUCTION

Failures in power systems are mostly induced by electrical insulation damages, for example in transformers, cables and their accessories. Insulation damages are caused by defects in the solid dielectric insulating media. Many kinds of defects can be appeared in solid insulating media such as protrusions, small metallic contaminations and gas-filled voids during the manufacturing process, and cracks and erosion caused by thermal stress and degradation by partial discharge during operation. Diagnosis of solid dielectric insulation, especially during operation, is a vital part to guarantee a reliable power supply. Various diagnostic techniques such as the measurements of dielectric properties and detection of partial discharge have been intensively developed and are now state of the art. Recently, it has been focused that diagnosis using electro-magnetic wave can be applied for non-destructive and spatial resolved condition assessment in insulating systems [1-4].

Detection and frequency analysis of electro-magnetic wave radiated from partial discharge in epoxy resin were investigated. Electro-magnetic waves radiated from partial discharge could be detected using simple system with a conventional discone antenna and a spectrum analyzer in our previous work [5-8]. In the present work, we have investigated detection and frequency analysis of electromagnetic wave caused by partial discharge in various solid insulating media not only epoxy resin including silica filler but also cross-linked polyethylene.

2 EXPERIMENTAL DETAILS

A block made from epoxy resin was used as a specimen for electrical treeing. Two types of solid dielectrics for electrical insulation were used. One is thermal cured epoxy resin with silica powder (average diameter 30~40 μm) and another is polyethylene in 2mm in thickness cross-linked by electron irradiation. A Ni-plated steel needle electrode with a tip of 35 μm radius of curvature was included and a void with about 0.5 mm of length at the needle tip was made in the specimen. A specimen was placed on a brass plane electrode with a diameter of 50mm in insulating oil.

Fig.1 shows experimental setup for the present work. Upon applying ac voltage (f=60 Hz), the voltage was monitored by a digital oscilloscope (Yokogawa, DL-1740, 500 MHz, 1 GS/s) using a capacitive divider, and the discharge current signal detected by a resistance (50 Ω) was traced. Electrical tree development was checked by using optical microscope and a digital camera with every 10 min interval.

Detection of electro-magnetic waves caused by partial discharge in epoxy resin related with void discharge and electrical tree development was used by a discone antenna (D130, Dai-ichi Denpa Kogyo, frequency range: 25~1300 MHz). Frequency spectrum was obtained by using two different methods; one was using a spectrum analyzer (Hewlett Packard HP8590E) and another was by FFT of detection signal by the antenna through a digital oscilloscope. By using a latter method, frequency spectra radiated from partial discharge in positive and negative polarity during ac voltage application were obtained in separation. The antenna was located at a vertical distance of 0.15 m and a horizontal distance of 0.45 m from the gap.

All measurements were carried out in a laboratory without electro-magnetic shielding.

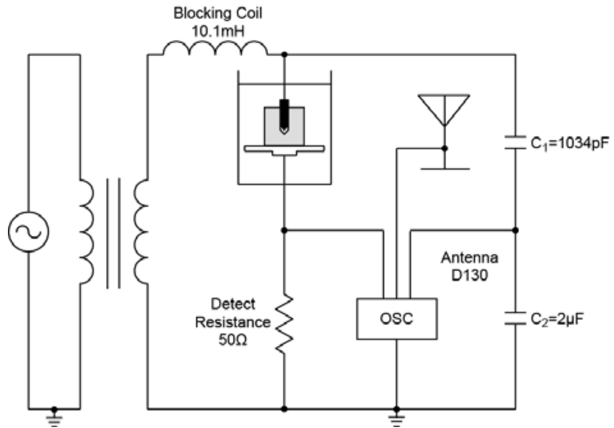


Figure 1: Experimental setup in this work.

3 EXPERIMENTAL RESULTS AND DISCUSSION

3.1 EM Wave of External Noise and EM Waves from Partial Discharge in Air and in Oil

In the present work, electro-magnetic wave (EM) spectrum measurements were not carried out in a laboratory with electro-magnetic shielding. At first, characteristics of EM spectrum by external noise should be clarified. EM spectrum of the external noise was taken under the condition without any voltage application to the specimen. The EM waves were detected at around *f*=77 MHz and *f*=390 MHz. These EM frequencies were observed for the measurements under the different conditions (date, time etc.). Hereafter, these frequency components were attributed by the external noise.

To clarify specific frequency components in EM waves from partial discharge in epoxy resin, frequency components on partial discharge in air and in oil have been also investigated by using needle-plane electrode configuration. Specific frequencies were detected only at below *f*=50 MHz and *f*=80~90 MHz. Detected frequencies of EM waves from partial discharge in oil were below *f*=50 MHz, around *f*=70~90 MHz which were similar to those in air. Furthermore, EM waves were detected dispersively in the region of *f*=100~200 MHz and it was enhanced with increasing partial discharge level, leading to the specific EM frequency of the partial discharge in oil.

3.2 EM Frequency Spectra of PD in Solid Dielectrics

Figure 2 shows EM spectra from partial discharge (PD) in positive and negative polarity for thermal cured epoxy resin specimen including 50 %-silica powder. The EM spectra just after ac voltage application (*t*=0 min) and after 20 min (*t*=20 min) are given in Figure 4. In this case, the EM waves with the frequency at around *f*=50 MHz and *f*=100~200 MHz were clearly detected. In addition, it seems that the frequency region of *f*=200~300

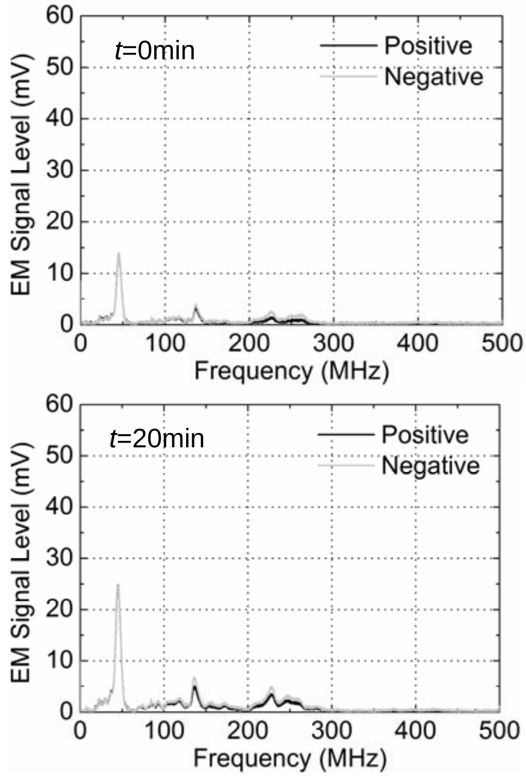


Figure 2: EM spectra of PD in epoxy resin

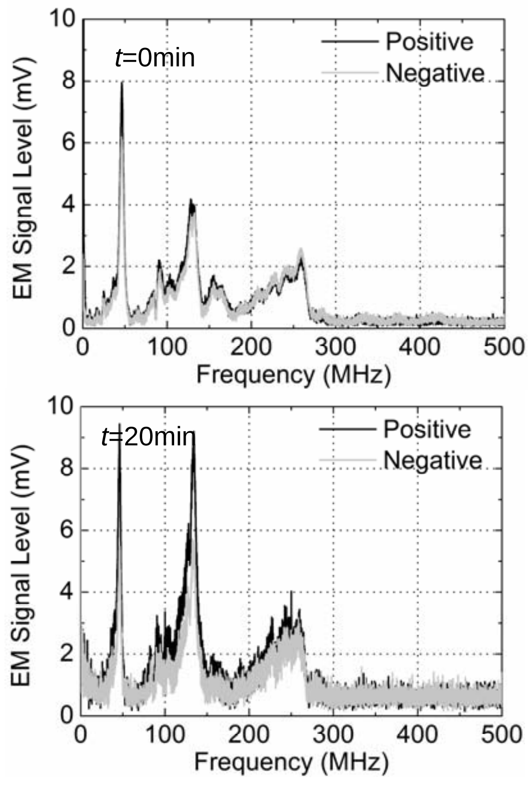


Figure 3: EM spectra of PD in polyethylene

MHz is detected very slightly. In this stage, electrical trees were not obviously generated in the microscope observation. Upon applying voltage with *t*=20 min, the traced EM spectrum at this time also seen in Figure 2 is not different from that obtained at *t*=0 min. Namely, the EM waves in the regions around at *f*=50 MHz and *f*=100~200 MHz were detected. However, the EM levels of these frequency components were intensified. Especially, the EM level of f=200~300 MHz were enhanced and it was clearly observed. This frequency component is different from those of PD in air and in oil mentioned in previous work [5,7]. The EM frequency spectrum and its behavior are almost same in both polarities.

Frequency spectra from PD in cross-linked polyethylene specimen are indicated in Figure 3. Though EM level of PD in cross-linked polyethylene is lower than that in epoxy resin, radiated EM frequency spectra and their behavior are not essentially different from those in epoxy resin.

From these findings, the lower frequency components of f=50 MHz and f=100~200 MHz and higher frequency component of f=200~300 MHz may be caused by the void discharge and partial discharge associated with tree development in solid dielectrics. It will be useful for detection PD and diagnosis of solid dielectrics using the specific frequencies for partial discharge.

3.3 Integral EM Level of Specific Frequency Regions

To make clearer the specific frequency of PD in void and PD associated with electrical tree development, integral EM level for some frequency regions has been investigated. It should be noted that integral EM level for three frequency regions of f=40~100 MHz, f=100~200 MHz and f=200~300 MHz were taken from the frequency spectra for epoxy resin and cross-linked polyethylene indicated in Figure 2 and Figure 3 with baseline correction, respectively.

Figure 4 shows change in integral EM levels during void discharge and electrical tree development for f=40~100 MHz, f=100~200 MHz, f=200~300 MHz and f=300~400 MHz for epoxy resin mixed with 50%-silica powder is shown. And optical microscope images during electrical tree generation and development are shown in Figure 5, and it is corresponding to change in integral EM level indicated in Figure 4.

Just after ac voltage application (t=0 min), at this stage, electrical tree generation was not observed in the microscope image. So, it is considered that only void discharge occurred in the epoxy specimen. In this stage, the integral EM levels for f=40~100 MHz and for f=100~200 MHz were relatively low. The integral EM level for f=40~100

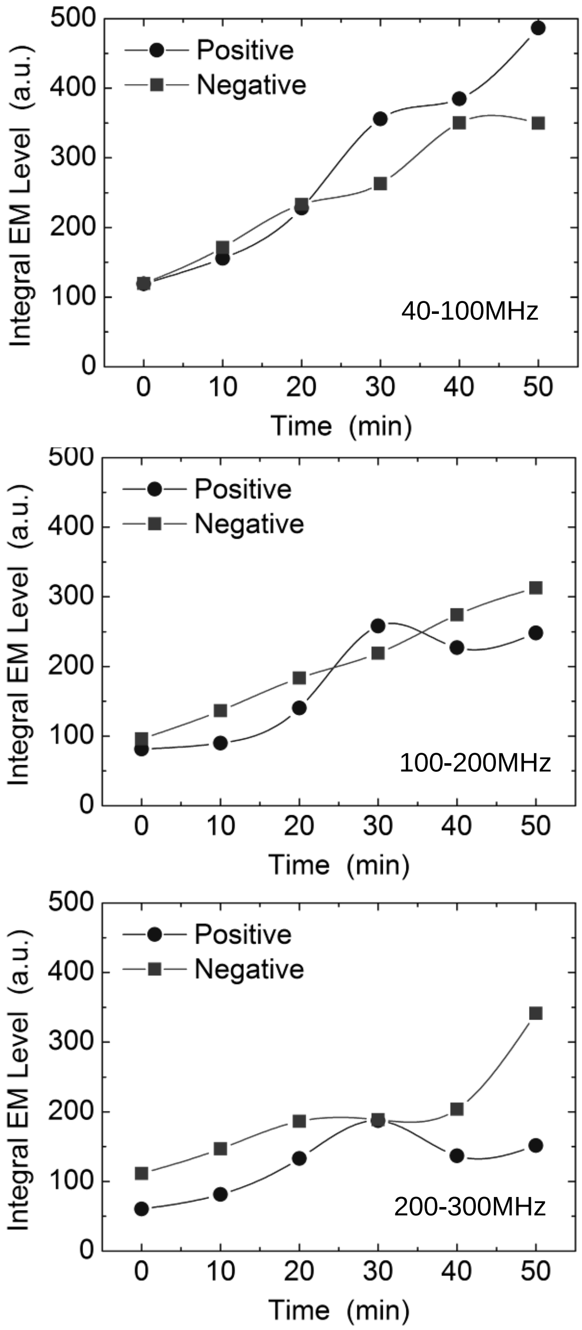
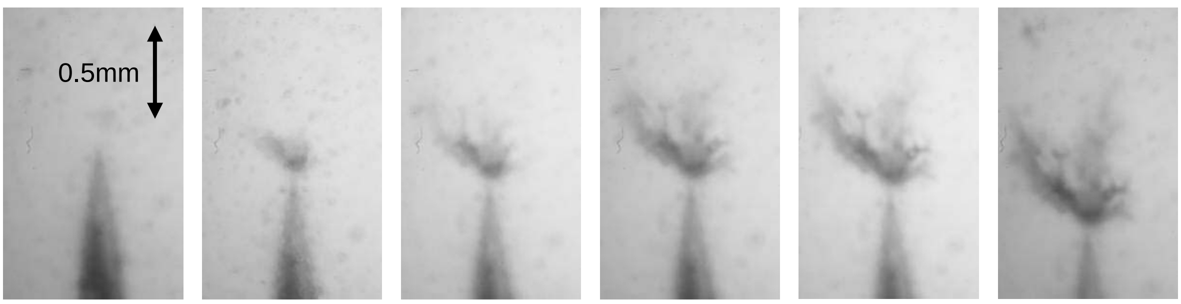


Figure 4: Change in integral EM level during tree development in epoxy resin



t=0min t=10min t=20min t=30min t=40min t=50min

Figure 5: Electrical tree development in epoxy resin

MHz increased monotonically during tree development though there was observe time region with small change in integral EM level.

On the contrary, the integral EM level for *f*=100~200 MHz were enhanced at *t*=0~30 min, and then they were almost same or were reduced at *t*=30~40min. At *t*=50 min, the integral EM level increased again. This change of integral EM level is consistent with tree generation and growth. Namely, as is seen in Figure 5, electrical tree generation at tip of the void is recognized after *t*=10 min voltage application. Trees grew with voltage application for *t*=10~30 min, and then tree growth interruption stage is observed for *t*=30~40 min. The re-growth is clearly observed at *t*=50 min.

The behavior of integral EM level for *f*=200~300 MHz was almost same as that for *f*=100~200 MHz. So that it is considered that the higher frequency components will be detected according to the progress of electrical tree and degradation of dielectric insulation.

Change in integral EM levels and electrical growth image for cross-linked polyethylene are shown in Figure 6 and Figure 7, respectively. Change in the integral EM levels is similar to that obtained for epoxy resin specimen. However, in this case, the behavior of the integral EM level is well correspond to electrical tree generation and growth in comparison with that obtained for epoxy resin specimen.

3.4 Relationship between Integral EM Level and PD Charge

It is important that clarification of integral EM level for specific frequency region and PD level from viewpoint of PD detection and insulation diagnosis in practical application. Figure 8 and Figure 9 show relationship between PD charge and integral EM level for three frequency regions. Here, the PD charge was estimated by integral of the first PD current pulse obtained for each polarity.

Integral EM level is almost proportional to PD charge regardless of frequency region, polarity and solid dielectric material.

In focusing on polarity difference, the dependency has almost same coefficient for the frequency region of *f*=40~100 MHz. However, in the higher frequency regions of *f*=100~200 MHz and *f*=200~300 MHz, which should be associated with

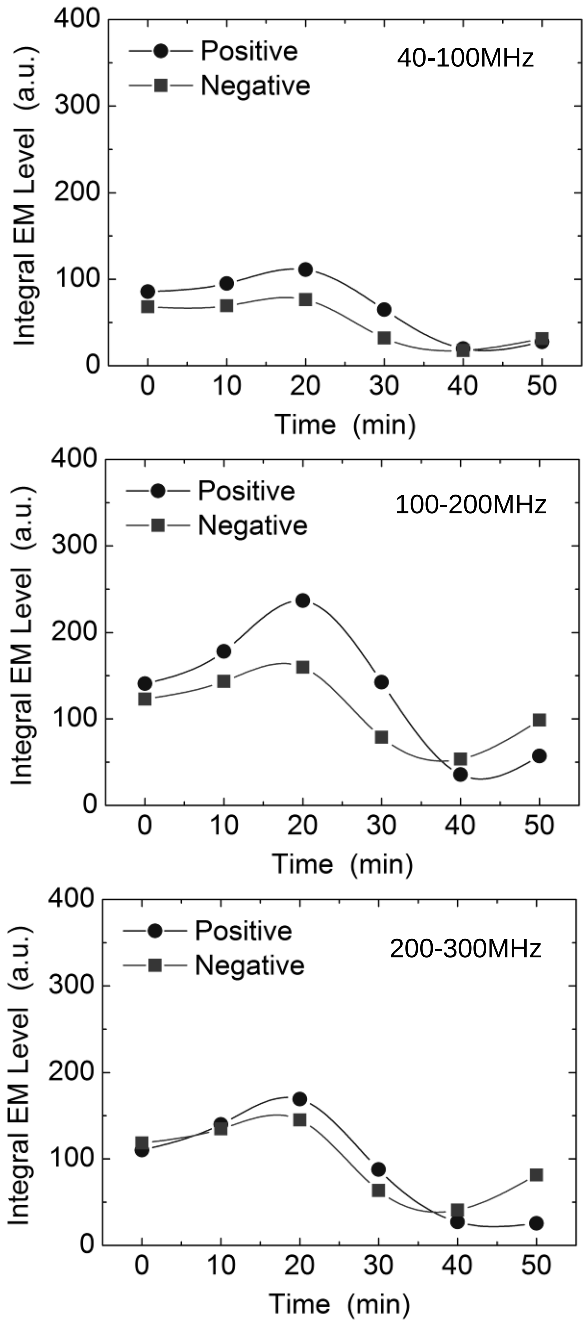
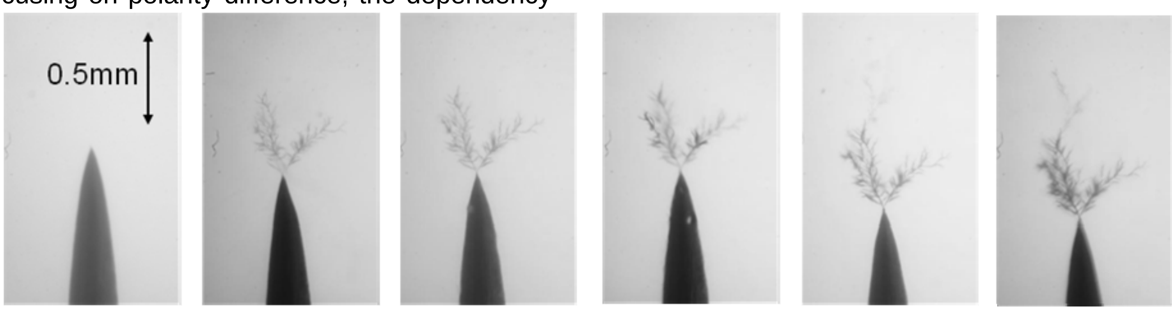


Figure 6: Change in integral EM level during tree development in polyethylene



t=0min *t*=10min *t*=20min *t*=30min *t*=40min *t*=50min

Figure 7: Electrical tree development in polyethylene

electrical tree growth, the coefficient of positive polarity is significantly just smaller than that of negative polarity. This reason is not clear in this stage. But it may result from the fact that tree growth is dominantly influenced by positive PD and positive PD has higher discharge current compared with negative one.

4 DISCUSSION

The specific EM frequency region for the electrical tree development is higher than those for partial discharges in air and in oil and for void discharge in resin. This fact is interpreted by the difference of dielectric strength. Solid dielectric materials have higher dielectric strength than air and oil, because it has higher density and strong molecular bond. Therefore, higher energy and higher electric field is needed for electrical tree generation and development, resulting in high electron velocity and high rise time of PD current which will be related to the EM frequency. This interpretation is supported by our investigation for partial discharge current measurements [6,7]. On the other hand, no difference in specific EM frequency components between for epoxy resin and cross-linked polyethylene, because basically these solid organic dielectric materials consist of almost same molecular bonds and binding energies such as C-H, C-C etc.

In addition, electrical tree escalates with some

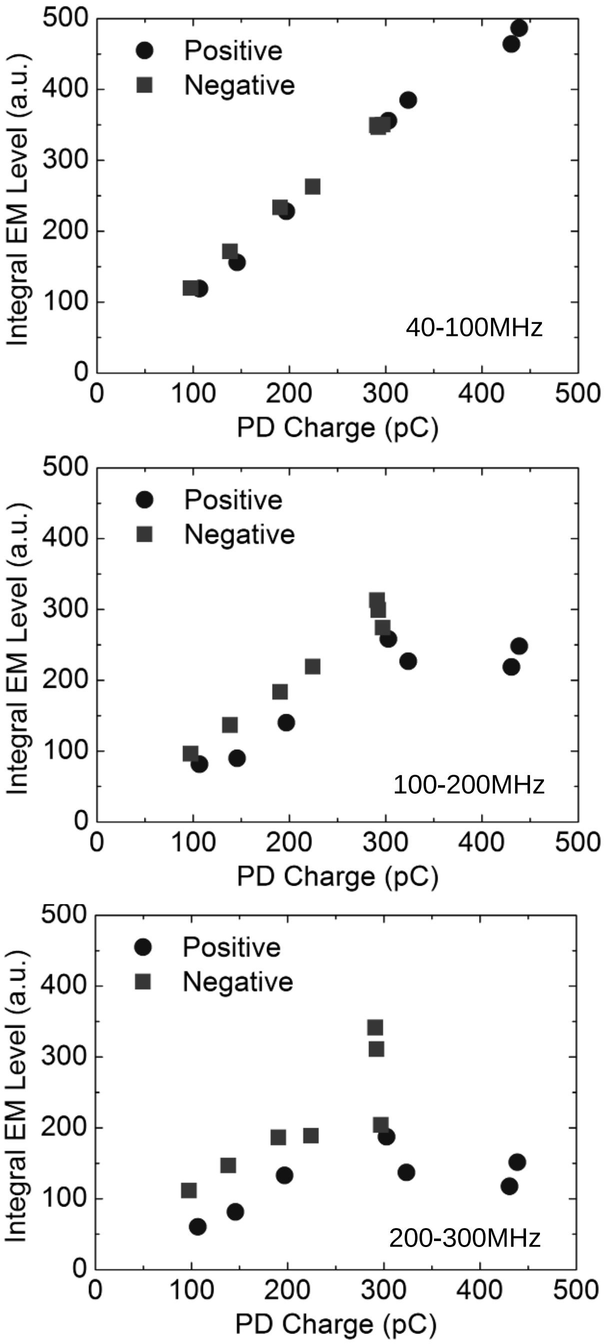


Figure 8: Relationship between PD charge and integral EM level in epoxy resin

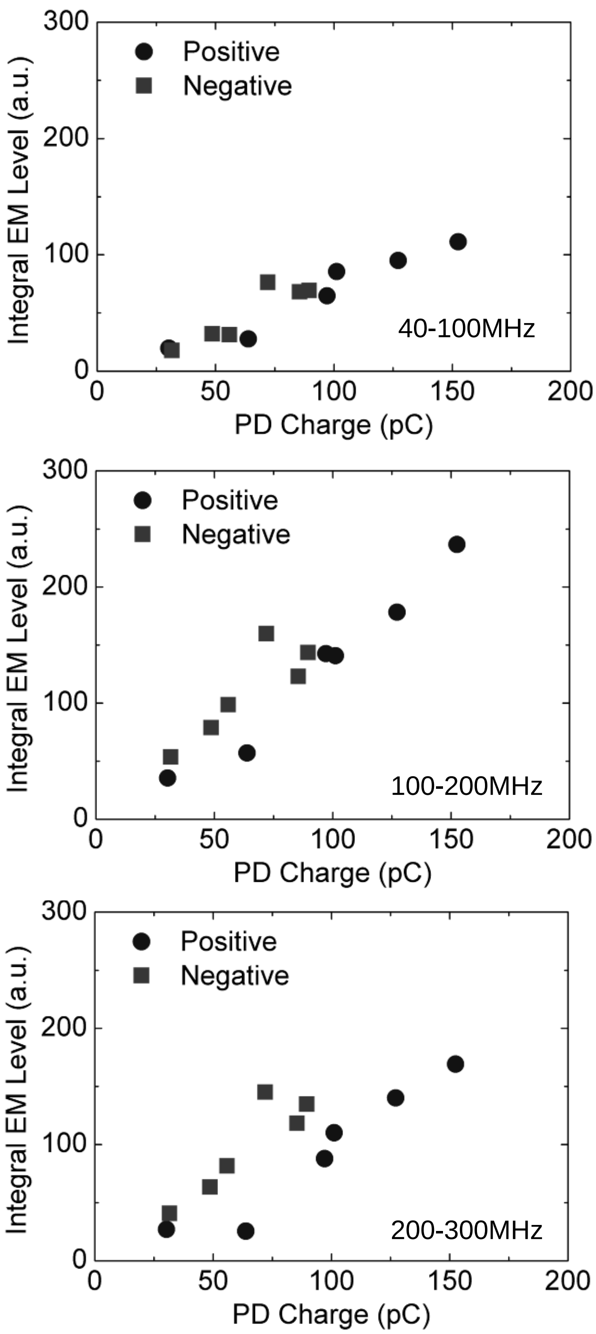


Figure 9: Relationship between PD charge and integral EM level in polyethylene

interval due to up-and-down of pressure and discharge voltage in tree channel [8] and the electric field at the tip of tree channel increases with tree development. This tree growth mechanism suggests that the specific EM frequency shifts to higher region.

5 CONCLUSION

In the present work, we have investigated detection and frequency analysis of electromagnetic wave caused by partial discharge in various solid insulating media not only epoxy resin including silica filler but also cross-linked polyethylene.

Partial discharges in solid dielectric insulators can be distinguishable by using specific frequency of detected electromagnetic wave. And the higher frequency components are associated with the progress of electrical tree and degradation of dielectric insulation. By focusing the above-mentioned specific electro-magnetic frequencies and their signal levels, especially at higher frequency components, it is useful for detection of partial discharge and insulating assessment for power equipments, cables and their accessories consisting of solid insulation media such as epoxy resin and polyethylene.

6 ACKNOWLEDGMENTS

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