Time and spatial-resolved spectroscopic measurement system of PD light emission and its application to observation of PDs in SF_6 gas

Yuta NAKAYAMA, Mohamad KAMAROL, Tomoki HARA, Masayuki HIKITA and Shinya OHTSUKA
Kyushu Institute of Technology, Kitakyushu, JAPAN

***Abstract*- This study is aimed to sophisticate the simultaneous measurement system of electrical and optical information of PD phenomena, *i.e.* PD current and PD light emission phenomena. Using this sophisticated system, we can discuss and clarify the breakdown mechanism as well as the discharge condition such as streamer and leader discharge in SF_6 gas or new SF_6 substitute, based on observation results.**

In this paper, we described the structure and significance of the time and spatial-resolved spectroscopic measurement system. Then, we showed the measurement concept of PD phenomena and the main results obtained from this system with an electrode system forming non-uniform electric field in SF_6 gas under ac high voltage application.

I. Introduction

So far, we have investigated partial discharge (PD) phenomena from the initiation of PD to the breakdown of mixture gas including SF_6, PFC gas, and single gas of CO_2 or N_2 (including the effect of the electrode coating) by electrical and optical simultaneous measurement to examine application possibility as SF_6 substitute gas [1]-[3]. From the viewpoint of improvement of the insulation diagnosis of the gas insulation apparatus, there is a demand to examine in more details the discharge phenomenon in SF_6 gas. We have investigated PD light emission properties by time-resolved spectroscopic measurement system [1] and other researchers have also investigated them by the similar system [4]. However, these systems only allow as to observe the PD light emission properties at the slit position, not giving the spatial information of the whole discharge image. In this study, we developed electrical and optical simultaneous measurement system that allows time and spatial-resolved spectroscopic measurement by adding a framing ICCD camera to a conventional streak camera and spectroscope [1] to investigate partial discharge characteristic in SF_6 gas.

In this paper, we described a construction purpose and the significance of this system, and then we showed gas pressure *P* dependence of breakdown and the PD inception voltages of SF_6 gas under the AC voltage application and optical observation results of the light emission of PD using the developed system.

II. Time and spatial-resolved spectroscopic measurement

Fig.1 shows a flowchart of the time and spatial-resolved spectroscopic measurement process. The wavelength of the optical filter to perform spatial-resolved spectroscopic measurement is determined by the results of the time-resolved spectroscopic measurement of the conventional streak camera and spectroscope [1] of the discharge properties of SF_6 gas. The optical filters corresponding to a specific wavelength were mounted with each framing ICCD camera .The framing camera with the optical filter allows the acquisition of spatial-resolved discharge light emission image at a given time. Observed optical image results enable us to elucidate discharge phenomenon from PD to BD and apply to insulation diagnosis of gas insulated power apparatus.

III. Experimental setup and procedures

Fig.2 shows the experimental setup for electrical and optical simultaneous measurement system that allows time and spatial-resolved spectroscopic measurement. The optical system is composed of framing ICCD camera (Hamamatsu, C7977) consisting of three ICCD cameras, spectroscope (Hamamatsu, C5094) and streak camera (Hamamatsu, C7700). This optical measurement system allows the acquisition of not only temporal development of the discharge light emission

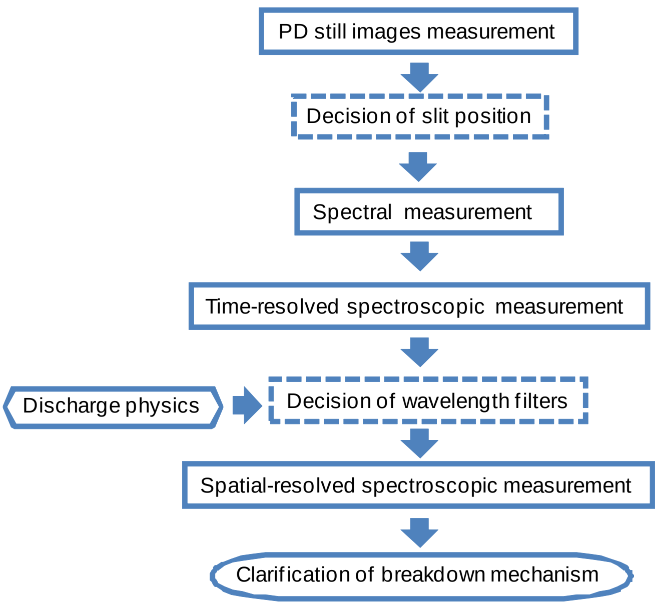


Fig.1.Flowchart of time and spatial-resolved spectrometric measurement

978-1-4244-2549-5/$25.00 © 2008 IEEE

image but also the wavelength resolution image of the discharge light emission at an arbitrary time by changing the wavelength of the optical filters. The wavelength of the filter was determined by PD light emission spectrum measured by the spectroscope and the optical properties of discharge type.

Therefore, this optical observation system allows time and spatial spectroscopy for PD phenomenon before reaching a breakdown and the identification of the discharge type from the initiation of PD to breakdown. PD light emission as well as spectrum information on each discharge type from the view point of gas insulation characteristic may also deduced. Two sets of electrodes system (needle and needle electrodes, needle and plane electrodes: gap length 10 mm) were used in the experiments. The each electric field utilization factor is η=6.9 %(needle-plane electrode) and η=7.3 %(needle-needle electrode). We measured the difference of the discharge characteristic by such different electrode systems.

Spectroscopic spectrum was measured at the two different slit positions as Position A (very close to the needle-tip) and B (away from the needle-tip) as shown in Fig.3. Position B was determined with the development pattern of the discharge light emission image under the experiment conditions. We used the UV lens whose transparent wavelength is more than 300 nm when we measured PD light emission spectrum.

In this experiment, we used two kinds of the optical filters with transmission wavelength ranging between 580 nm - 2,000 nm (Red filters, transmittance: 91.5 %) and 340 nm - 440 nm (Blue filters, transmittance: 80 %). It was reported that the light emission wavelength region of the streamer discharge

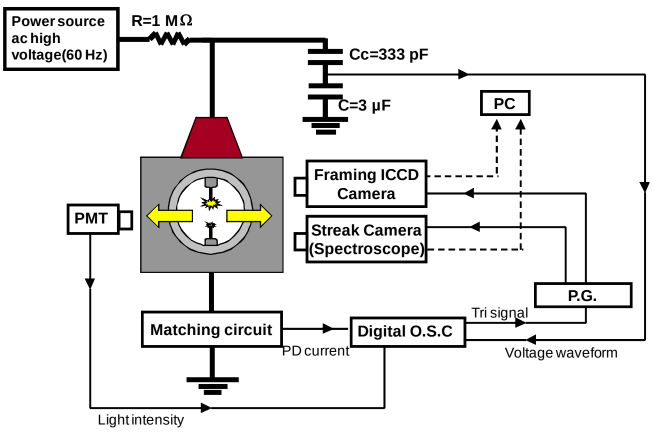


Fig. 2. Experimental setup

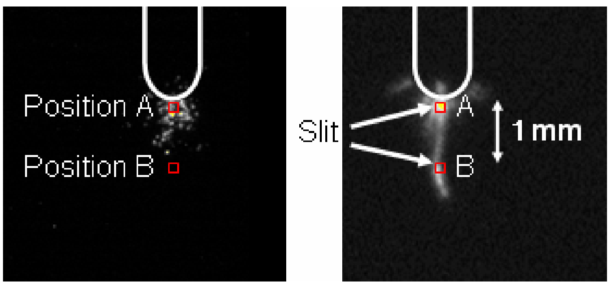


Fig.3. Slit position and typical examples of PD still images

Fig.4. Photograph of the filters

and leader discharge have each 400-500 nm and more than 600 nm, respectively [5]. According to this, we mainly used a blue filter and a red filter to separate the discharge type. We also used the narrowband filters of full width at half maximum (FWHM) as 10 nm, 40 nm, 80 nm. Fig. 4 shows the photograph of the filters.

IV. Results and discussion

Fig. 5 shows the gas pressure dependence of the positive and negative PD inception voltage V_{PD} , and breakdown voltage V_B in SF_6 gas. The electric field utilization factor of the two different electrodes system is approximately same, while the electric field distribution differs each other, leadings to different V_B-P characteristic (so-called N-shaped characteristic). In the needle to needle electrodes system, it is obvious in Fig.5 that the peak of the N-shaped characteristic spreads to the higher gas pressure region than the needle to plane electrodes system. The difference in V_B-P characteristics between the two kinds of electrode system would be attributed to space charge formation associated with the PD light emission.

Fig. 6 shows typical results of PD light emission image at P=0.1 MPa and different voltages (without inserting filter). It should be noticed that the light emission images were observed for an exposure time of 1 ms at the vicinity of the positive peak value of the AC applied voltage. Discharges were observed only with the lower electrode around PDIV (19 kVrms) at 0.1 MPa. When the applied voltage was increased to 25 kVrms, the discharges were observed at both electrodes. Furthermore, the discharges were observed at both electrodes around PDIV (30 kVrms) at 0.2 MPa and the PD emitting area was expanded when the applied voltage was increased to 45 kVrms. In the other hand, the discharges with the upper electrode were observed around PDIV (38 kVrms) when the gas pressure was increased at 0.3 MPa and discharges were observed at both electrodes when the applied voltage was

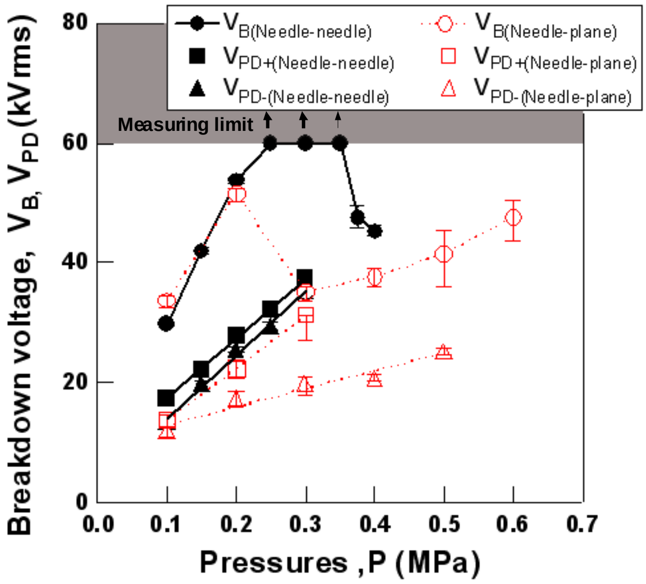
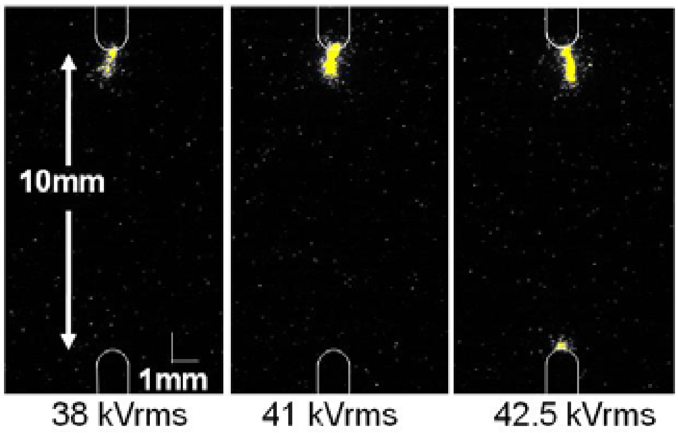
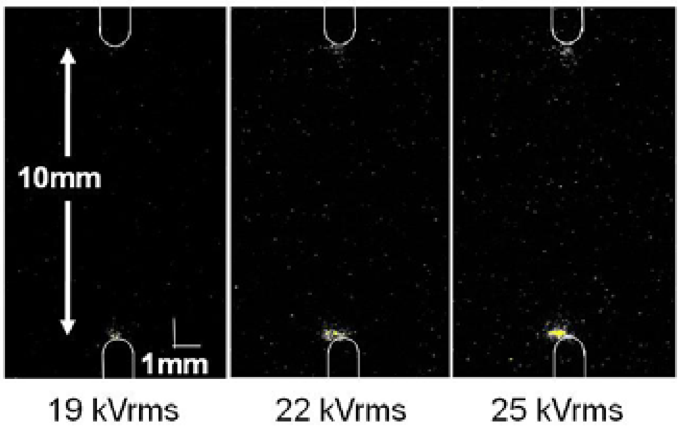


Fig.5. Gas pressure dependence of V_B and V_{PD} in SF_6 gas



(a) *P* = 0.3 MPa



(b) *P* = 0.1 MPa
Fig.6. PD light emission still images

increased to 43 kVrms. As shown in Fig. 6, discharge light emission images were observed even from the lower electrode for needle-needle electrode system. The characteristics for needle-needle electrode system to give rise to different N-shape characteristic of V_B-P compared with that the needle-plane electrode. Since discharges were developing a few mm in length as shown in Fig.6 (a) at 43 kVrms, the slit position and measured PD light emission spectrum has been set at this condition. Fig.7 shows typical results of spectrum of PD light emission image during 1μs in SF_6 gas at 0.3 MPa and 43 kVrms at Position A and B, respectively. Note that the light emission spectrum can be observed at Position B only when PDs extend a few mm and passes the slit Position B. Thus the rate of obtaining light emission image at Position B is lower compared with case at Position A. Fig. 7(b) were integrated each 12data (Position A), 5data (Position B) and standardized it with the greatest value. PD light emission spectrum is observed for wide band of 300-600 nm in Position A. However, there are few spectrums over 500 nm at Position B. We used framing ICCD camera to measure such spatial wavelength distribution.

Fig. 8 shows the wavelength band of the optical filters we used for experiments, and each filter corresponds to the emission spectrum band of the streamer discharge and leader discharge.

Fig. 9 shows the PD light emission images that have been measured by spatial-resolved spectroscopic measurement system. Fig. 9 (a) to (c) shows the results of the simultaneously obtained time and spatial-resolved spectroscopic measurement using the red filter, without a filter, and the blue filter, respectively.

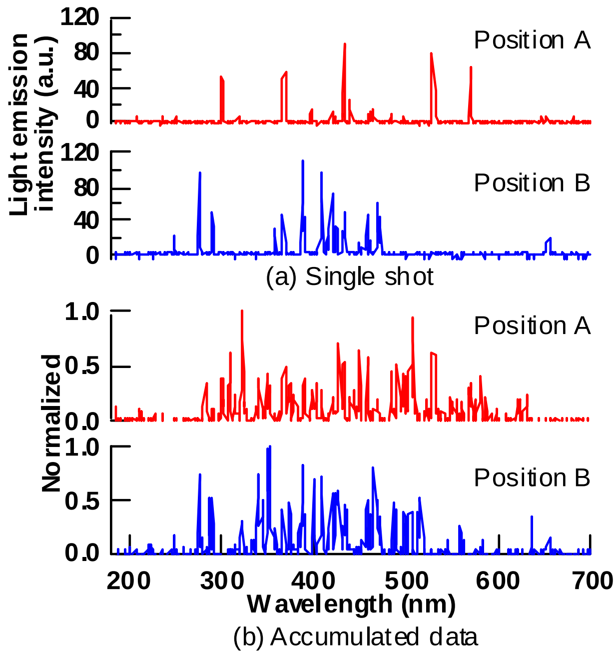


Fig.7. PD light emission spectra in SF_6 gas at 0.3 MPa

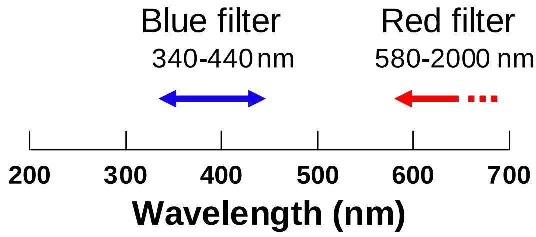


Fig.8. Wavelength band of filters

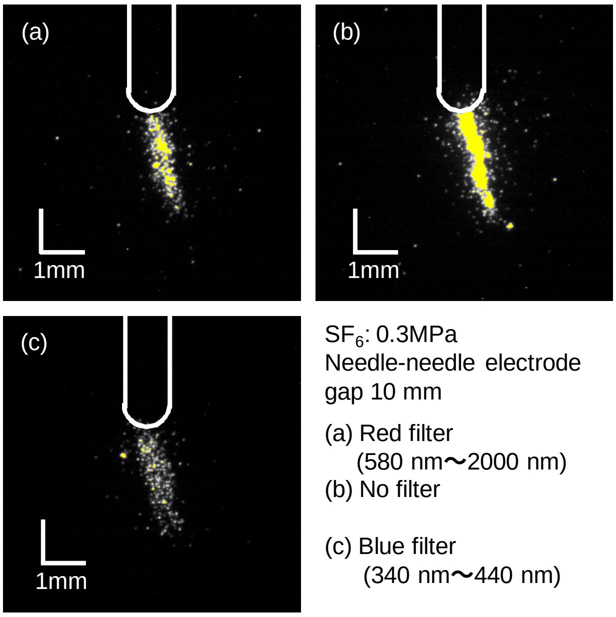


Fig.9. Spatial resolved PD light emission images with different wave filters in SF_6 gas

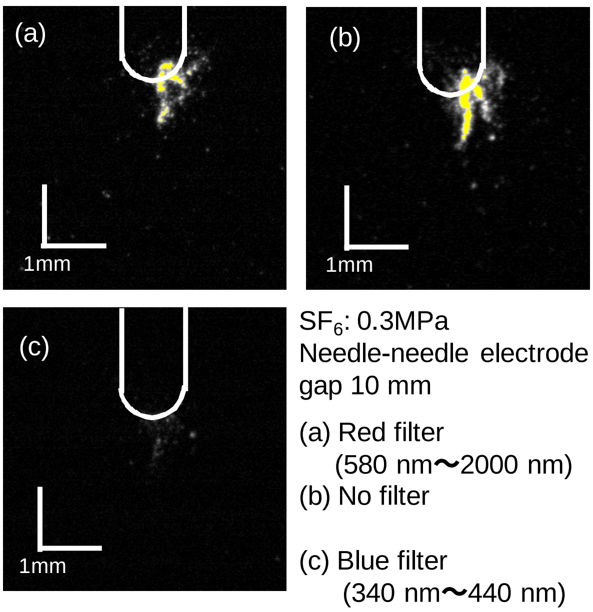


Fig.10. Spatial resolved PD light emission images with different wave filters in SF_6 gas

In Fig.9 (a), the PD light emission image was relatively strong at the center of the discharge using the red filter, but in Fig.9(c), the PD light emission image was observed at such range as without filter image by the blue filter. In Fig. 10, the similar result was shown.

It is seen in Fig.9,10 that the intensity of light emission with the filter is relatively lower compared with that without filter. Experimental results revealed that PD light emission intensity for one of red or blue filter was lower than that for the other case. It means that one can perform space-resolved spectroscopic analysis by selecting an appropriate filter.

When we used the narrowband wavelength filters (FWHM=10 nm), we could observed discharge image by the filter of center wavelength 480 nm, but we could not observe it by the filter of center wavelength 405 nm and 600 nm.

Thus, it is important to select optical filter where in the future, we will investigate insulation diagnosis technology based on the discharge type.

V. Conclusions

We have developed electrical and optical simultaneous measurement system allowing time and spatial-resolved spectroscopic measurement by adding a framing ICCD camera to a conventional streak camera and spectroscope to investigate partial discharge characteristic in SF_6 gas.

As a result, the slit position dependence of the PD emission spectrum was confirmed and the results of measured PD light emission image that made a spectrum spatially, could confirm spatial spectroscopic with the optical filter.

Acknowledgment

This study was partially supported by a Grant-in-Aid for Young Scientists (A) (No.18686025) from The Ministry of Education, Culture, Sports, Science and Technology, Japan.

References

[1] S.Ohtsuka, K.Eguchi, M.Cho, S.Yuasa, S,Okabe and M.Hikita, “Light emission properties of SF_6 gas mixture in impulse breakdown process”, XIIIth International Symposium on High Voltage Engineering, Delft, Netherlands, 445(2003)

[2] S.Ohtsuka, M.Koumura, K.Eguchi, M.Hikita, et al. : “PD inception and breakdown voltage characteristics in PFC and SF_6 gas mixtures”, *Gaseous Dielectrics IX*, pp.211-216 (2001)

[3] S.Ohtsuka, M.Koumura, M.Cho, Y.Hashimoto, M.Nakamura and M.Hikita : “Insulation properties of CO_2/N_2 gas mixture with a small amout of SF_6”, *Gaseous Dielectrics IX*, pp.295-300 (2001)

[4] H.Kojima, Y.Ohta, S.Yoshida, H.Hayakawa, F.Endo and H.Okubo, “Partial Discharge Mechanism by Spectrum Measurement under Impulse Voltage Condition in SF_6 and Gas Mixtures”, XVth International Symposium on High Voltage Engineering, Slovenia, T7-182(2007)

[5] T.Flohr, W.Pfeiffer, C.Zender and V.Zimmer: “Diagnosis of Prebreakdown Phenomena in SF_6 in Non-uniform Gaps for Very Fast Transient Voltage Stress”, *Conference record of the 1994 IEEE International Symposium on Electrical Insulation*, Vol.27, No.3, pp.603-606 (1994)