Light Emission Spectrum Depending on Propagation of Partial Discharge in SF_6

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Abstract- **An understanding of mechanism of Partial Discharge (PD) in SF_6 gas is critical for diagnosis of PD in electric power equipment. Moreover, analysis of PD mechanism contributes to the optimization of the design of electric power applications. For these reasons, we study in detail about PD mechanism by measuring light emission spectrum of PD in SF_6 gas.**

In this paper, under an application of lightning impulse voltage in needle-plane electrodes, we have measured light emission spectrum of leader discharge. As the result, we have found out the light emission of long wavelength above 560nm in leader discharge, and the light emission above 560nm is emitted in the streamer head generated at the tip of the leader channel and radiated from dissociation products depending on the step propagation of leader discharge.

These results suggest that we can diagnose the PD propagation in SF_6 gas and estimate the risk of breakdown (BD) by measuring PD light emission spectrum in electric power equipment. There are possibilities to contribute to enhance performance of the diagnosis technique in gas insulated power equipment.

I. INTRODUCTION

In modern society, the gas insulated electric power apparatus represented by GIS is playing an important role of electric power supply. In order to attain the further environmental comfirmity and the cost reduction in these power apparatus, establishment of insulation diagnosis technique is called for strongly. Thus, for the purpose mentioned above, a clarification of partial discharge (PD) mechanism in SF_6 gas becomes important.

Generally, the PD in SF_6 gas is represented by repeat transition from streamer to leader discharge, at last results in breakdown (BD) [1-6]. However, since the PD under non-uniform electric field is complicated, the PD phenomena such as generating/progress characteristics are not clear.

In the basis of such a background, we have measured current and light intensity pulse waveforms of PD and acquired streak image of PD and PD light emission spectrum simultaneously using ultra high-speed synchronous PD measurement system.

In this paper, we pay attention to the relation between PD light emission spectrum and streamer/leader transition and discuss the change of the spectrum accompanying step propagation of PD.

II. EXPERIMENTAL SETUP

As shown in Figure 1, we apply positive lightning impulse voltage (1.2/50μs) at needle-plane electrodes (gap length g=40mm and 70mm) set in the gas tank filled up with SF_6 gas (0.1MPa) and generate leader discharge. Electrodes are made in SUS304 stainless steel, and tip diameter of needle electrode is 1mm. This electrodes system simulates the metalic particle in GIS. We measure the PD current waveform through the matching resistance and the PD light intensity waveform using the photo multiplier tube.

Simultaneously using the two sets of streak camera and a spectroscope connected to the one of the streak cameras, we can obtain ultra high-speed resolving images of PD and of light emission spectrum of PD to measure the detail information about PD such as inside gaseous condition, energy, and so on. Additionally we measure still image of PD using the digital camera connected to the image intensifier (I.I.) and the long distance microscope to amplify the light emission and to expand the view of tip of the needle electrode. By using above-mentioned ultra high-speed synchronous PD measurement system we can measure the PD phenomenon such as generation of streamer discharge and transition to leader discharge in nano-sec order.

III. LIGHT EMISSION SPECTRUM OF LEADER DISCHARGE

A. Experimental results of light emission spectrum of PD

It's shown in Figure 2 that the experimental results when we applied the lightning voltage of 109kV at the electrodes and measured the propagation of the leader discharge using the above-mentioned PD measurement system. Due to the application of impulse voltage, firstly, streamer discharge (PD_{1st}) is generated from needle tip. Next, the PD changes into leader discharge (PD_{2nd}) and after that PD_{3rd} occurs by repeating the streamer/leader transition. It can be seen the PD current and light intensity pulse synchronize with the streak image of each PDs. On PD_{2nd} and PD_{3rd}, a streamer head with strong light intensity occurs from tip of the leader channel which has the shape of thin and long filament as shown in Figure 2(b). Note that in the visible PD light emission spectrum the leader discharge (PD_{2nd} and PD_{3rd}) has long wavelength part (above 560nm), whereas the streamer discharge (PD_{1st}) does not have that as shown in Figure 2(e). This result would be result in the differences of the gas condition inside the PD.

B. Light emission spectrum of leader channel

As mentioned above, it turned out that the above 560nm wavelength region become remarkable in transition from

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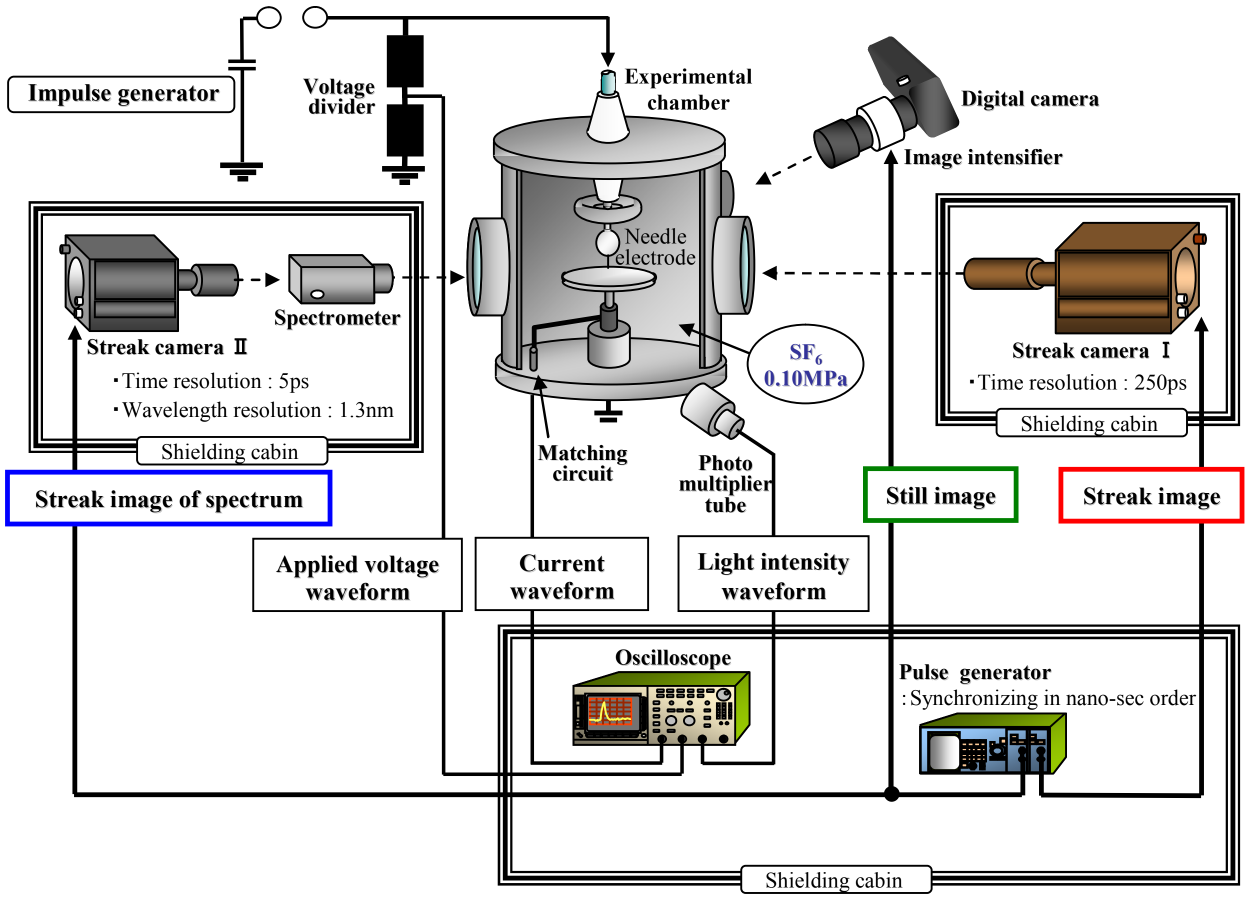


Fig.1 Experimental setup

streamer discharge to leader discharge. However, like PD_{2nd} and PD_{3rd} in Figure 2, leader discharge consists of two discharge parts such as the leader channel and the streamer head, thus the light emission spectrum of leader discharge is result of sum of the light emission from two discharge parts. To separate the light emission spectrum of leader channel from that of streamer head, we have measured the light emission spectrum of the leader channel using a cover plate set in front of the spectroscope to shade the light emission from the streamer head.

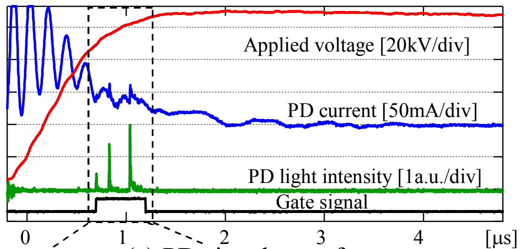
Results of that experiment are shown in Figure 3. Figure 3(a) and (b) show the light emission spectrum of leader channel and that of both parts for the integrated value of 5 different shots, respectively. Figure 3 indicates that the light above 560nm, which is a feature of leader discharge, is emitted from the streamer head occur in tip of leader channel.

C. Long wavelength light emission mechanism in leader discharge

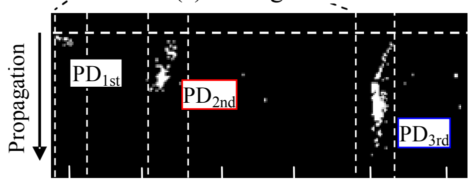
Most of the light emission above 560nm in streamer head will be radiated from dissociation products of SF_6 such as fluorine. In the ionization, electron attachment and dissociation process in SF_6 gas, dissociation products, e.g. SF_5, SF_4, SF_3, etc. is generated by dissociation of SF_6. Because fluorine is generated in each dissociation reactions, the majority of decomposition products is fluorine [7]. Moreover, such as 623.9nm, 634.8nm, 685.6nm, 690.2nm, and 703.7nm etc. are typical light emission spectrum of fluorine [8], and the measured long wavelength region spectrum of the leader discharge agrees with those wavelengths. For this reason, it is considered that long wavelength light emission in leader discharge is mainly radiated from the dissociation products of SF_6 such as fluorine.

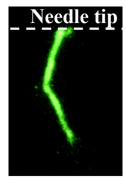
The reason why the long wavelength light emitted only from the streamer head but not emitted from leader channel can be explained by the difference of electron energy in the both discharge parts. In order to emit the long wavelength light as mentioned above, fluorine needs to be excited near 14eV [9]. In streamer head, electrons accelerated by large electric field inside of the streamer head collide with fluorine atoms and excite the ones to the energy level for about 14eV, so it is thought that the long wavelength light emits in accordance with de-excitation of the exited fluorine atom.

On the other hand, in the leader channel, because of its internal high conductivity and low electric field, it would be hard to be accelerated up to the energy level enough to excite fluorine atoms. Such results imply that there is a difference of the electron energy distribution inside between the leader channel and the streamer head.

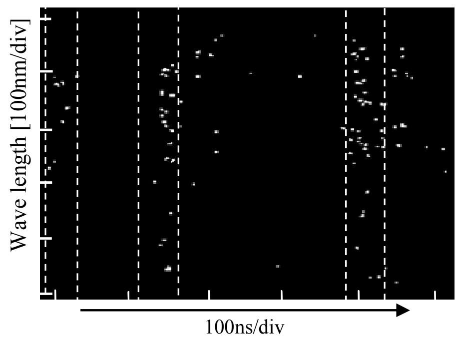


(a) PD signal waveforms

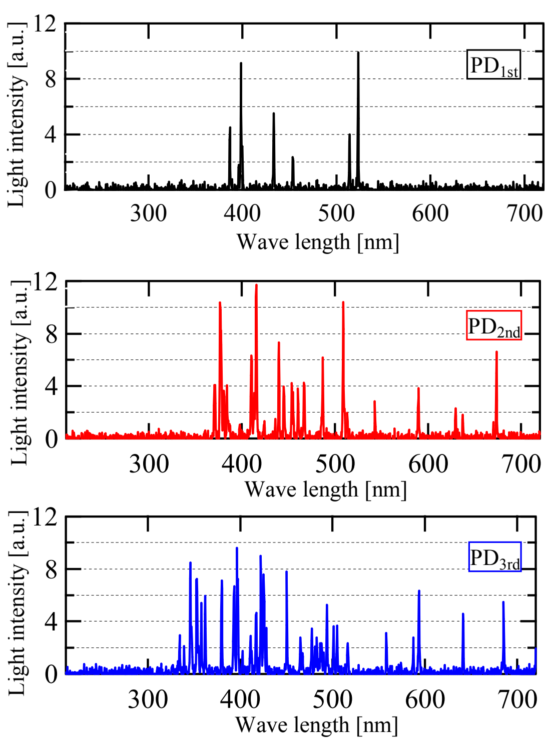




(b) Streak image of PD (c) Still image of PD

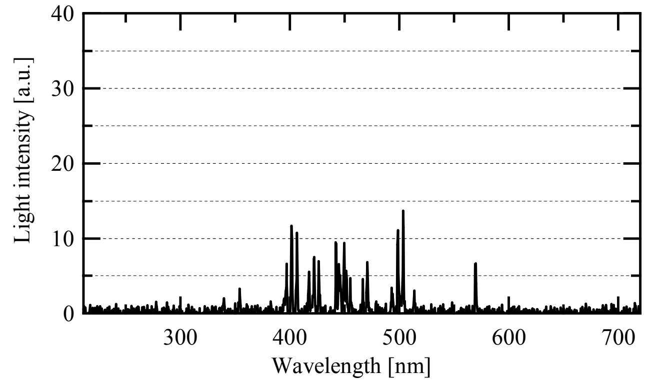


(d) Streak image of PD light emission spectrum

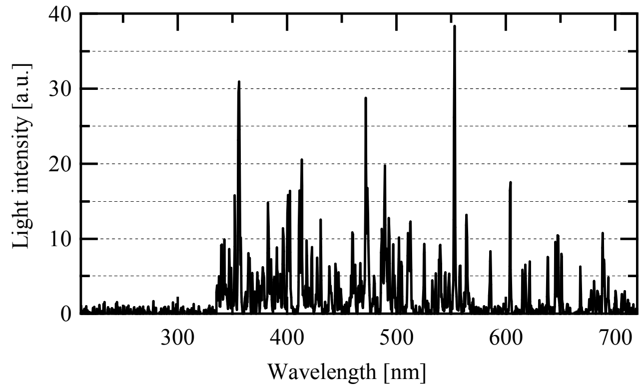


(e) PD light emission spectrum

Fig.2 Experimental results



(a) Spectrum of leader channel



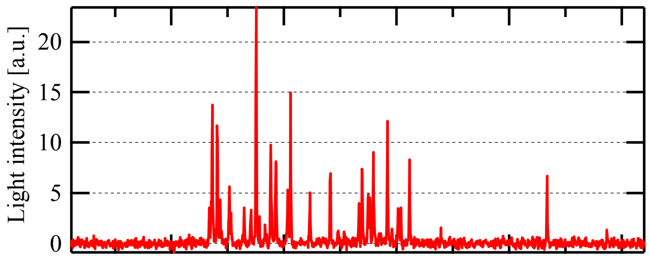
(b) Spectrum of leader channel and streamer head

Fig.3 Comparison of light emission characteristics

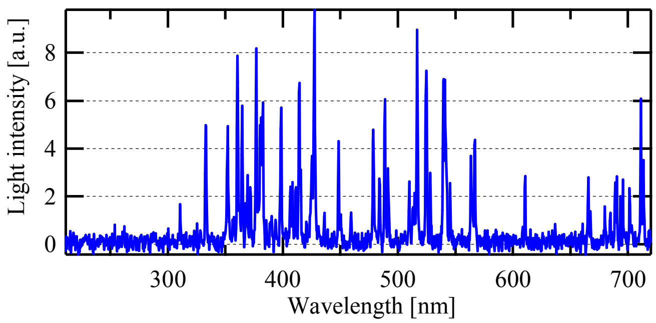
IV. Light Emission Spectrum Depending on Propagation of Leader Discharge

In order to consider the relation between the long wavelength light emitted from the streamer head and development of the leader discharge, we have measured the light emission spectrum of leader discharge for longer gap length of 70mm under the higher voltage application. Light emission spectra of the leader discharge developing to PD_{5th} by repeating streamer/leader transition are shown in Figure 4. The rate of the long wavelength light intensity (I_{long}) to the whole visible light intensity (I_{total}) changes accompanying the step propagation of the leader discharge.

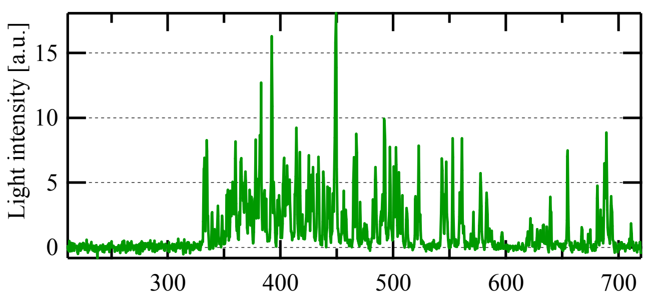
We show the dependence of I_{long}/I_{total} on step number of leader discharge propagation in Figure 5. In Figure 5, data 1 and data 2 correspond to the results of Figure 2 and Figure 4, respectively. I_{long}/I_{total} increases with the step propagation of leader discharge, then it rises to the peak and decreases, and PD terminates. This tendency would imply that the decomposition products decrease prior to the end of the step propagation of leader discharge. Since the I_{long}/I_{total} indicates the amount of dissociation products of SF_6 by the PD energy of the preceding PD step, the decrease of I_{long}/I_{total} before the end of PD steps may show that the energy of streamer head attenuates in the case of leader discharge not resulting in BD.



(a) Spectrum of PD_{3rd}



(b) Spectrum of PD_{4th}



(c) Spectrum of PD_{5th}

Fig.4 Spectra of PD_{3rd}, PD_{4th} and PD_{5th}

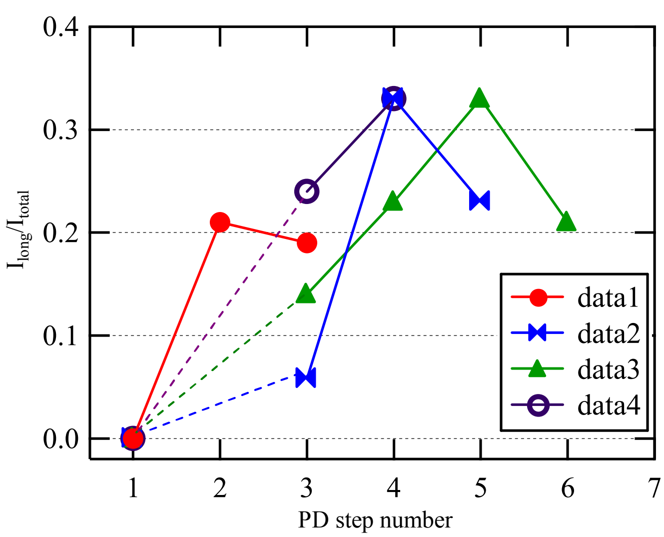


Fig.5 I_{long}/I_{total} as a function of PD propagation step number

V. Conclusion

In this paper, we have obtained the new knowledge as shown in below by measuring the light emission spectrum of the leader discharge in SF_6 gas and discussed the dependence of the light emission spectrum on the step propagation of leader discharge.

(1) By separating the light emission of leader channel from that of streamer head, we have found out that the long wavelength (560~720nm) light peculiar to leader discharge is emitted from the streamer head generated from the tip of a leader channel.

(2) The long wavelength light is mainly emitted from the dissociation products of SF_6 such as fluorine generated by the energy of the preceding PD. The difference of the light emission spectrum between streamer head and leader channel will imply the difference of the electron energy distribution.

(3) The PD light intensity ratio of long wavelength part to whole visible light (I_{long}/I_{total}) reduces before the end of PD propagation in the case of leader discharge without resulting in BD. This tendency may mean that the energy of PD is decreasing with the progress of PD.

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