THE EFFECT OF UV LASER IRRADIATION ON SURFACE FLASHOVER

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Abstract: The flashover along the interface of solid dielectric in vacuum is the limiting factor of the performance in high pulsed power devices, and there plenty of investigations about it in the past several decades. However, much of the work in the area of surface flashover has been devoted into determining which parameters are important in predicting flashover behaviour, and the theoretical understanding involved in the process is not yet mature. In this paper, the flashover performance of solid dielectric in vacuum was studied in the UV laser illuminated case. A testbed comprised of a pulsed high voltage supply, a vacuum chamber, and an excimer laser was assembled to test the flashover behaviour under pulsed voltage and UV laser irradiation. Finger electrode was used in our experiments for this kind of electrode is convenient to observe flashover events. The flashover voltages were measured for different illuminated positions on the insulator sample and unilluminated case. In conclusion, the UV laser irradiation induced surface flashover has different phenomena, which indicate some new mechanisms to interpret these experiment results.

1 INTRODUCTION

It has long been known that the dielectric/vacuum interface is electrically weaker than either the dielectric or the vacuum gap alone and hence may be the limiting element in a high voltage power transport system. From the viewpoint of engineering, it is an important problem to have a systematic analysis of flashover characteristics. There are a number of reports dealing with the effect of electrode materials, dielectric materials, the shape and size of insulators, the waveform of applied voltage, the degree of vacuum, the quality of metal-dielectric contact, the surface condition of the material and the magnetic field on the surface flashover [1]. Even if some of these reports get contradictory results, many of them predict the flashover behaviour well and provide useful design principles for insulator designers. Accordingly, different surface flashover models come forth to explain the experiment results. However, the essential mechanism involved in the process of flashover is still not clear so far.

The flashover performance of insulator in vacuum is seriously degraded if the dielectric/vacuum interface is exposed to ultraviolet radiation while voltage is applied [2]. Enloe and Gilgenbach have investigated UV-laser-induced dielectric surface flashover on several polymers under dc voltage in the 1980's. Recently, Javedani and Houck et al. also studied UV induced flashover to acquire empirical data on critical UV fluence, as it is important to design the power flow channel for explosively driven magnetic flux compression generators where the UV presence can be detrimental to power flow [3]. While the presence of such radiation plays a vital role in the pre-flashover mechanism for dc voltages, these radiations may not substantially affect the pulsed voltage performance [4]. However, it is not the case in our experiments when the insulator in under pulsed voltage and UV laser illumination.

2 EXPERIMENT SETUP

A testbed comprised of a pulsed high voltage supply, a vacuum chamber, and an excimer laser was assembled to test the flashover behaviour under pulsed voltage and UV laser irradiation. The synchronization of pulsed voltage and UV laser is controlled by DG 535. The optical system and high voltage system are shown in Figure 1. The laser beam is focused with a diameter of ~1mm to illuminate part of the insulator surface. The UV laser pulse width almost keeps constant for each experiment and the energy deviation is about 10%. A photodiode is used to measure the laser waveform and determine the time it arrives. The vacuum chamber was kept about 1×10^{-3} Pa during the experiment. Finger electrode used in our experiments is convenient to observe flashover events for this kind of electrode. The gap between two electrodes is kept constant all the time.

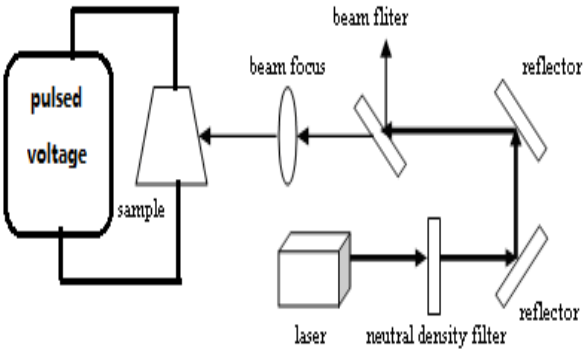


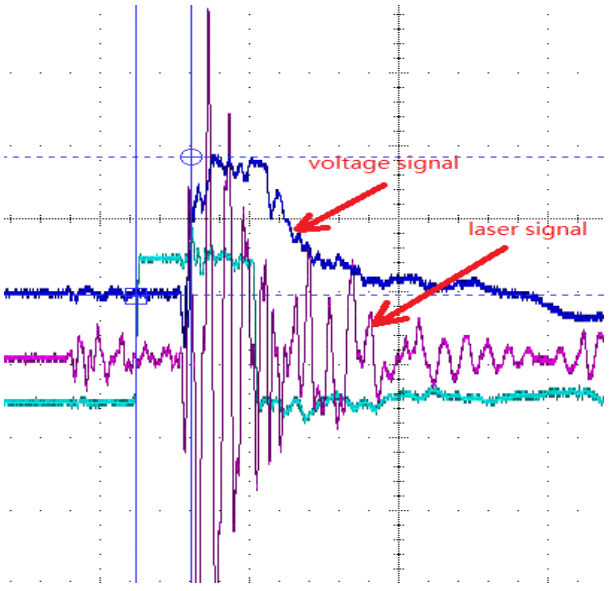
Figure 1: Sketch of the optical and voltage system

3 RESULTS AND COMPARISON

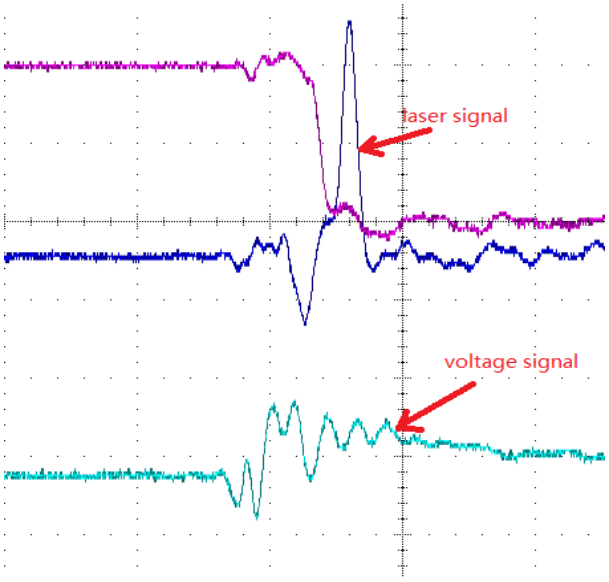
The insulator material used in our experiment is PMMA for it is easy to fabricate. The flashover voltage with no UV irradiation was measured for comparison. A preliminary experiment was done to evaluate the damage of sample during the flashover experiment. The sample was rest in the vacuum chamber for a period of time after a flashover experiment procedure has been done, then the procedure was done with the same sample. The results show that the sample will be damaged after about fifty flashovers occur (it is the anode electrode other than the sample was damaged during the experiment most of the time). So if the sample was not damaged, there is no need to use a new sample as it will bring in the electrode-insulator attachment effect. When the flashover occurs, the laser signal can not be detected as shown in Figure 2(a), so the laser signal can only be determined by the relative time delay to the trigger signal. The pressure is about $8\sim6\times10^{-4}$Pa when doing the self surface flashover experiment and UV induced flashover experiment. The sample was not changed during this group of experiments. The flashover voltages of self surface flashover and UV induced flashover are listed in Table 1 for comparison.

Table 1: Flashover voltages of self surface flashover and UV induced flashover

Case	First breakdown voltage/kV	Conditioned breakdown voltage/kV	Holdoff voltage/kV
Self surface flashover	25.2	25.2	21.2
UV induced flashover	23.2	22.4	16.8



(a)



(b)

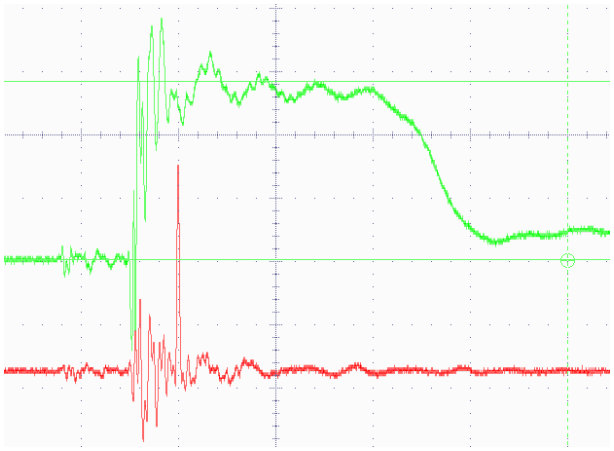
Figure 2: (a) and (b) are the flashover voltage signal and laser signal

In Hegeler's research, the lowest dielectric flashover voltage has been detected when the sample is irradiated with UV illumination near the cathode (the UV focal point has a diameter of approximately 0.5cm with its centre at the triple point where cathode, dielectric, and vacuum are in close proximity), When the sample is illuminated with UV irradiation in the middle of the gap (the electrodes are not irradiated), the dielectric flashover voltage amplitude increases by approximately 10% compared to the case where no UV illumination is applied [5]. This trend seems to be opposite with the previous researches done by Enloe and Javedani, all these researches are UV induced flashover under DC voltage although the experiment conditions may have some differences between each other.

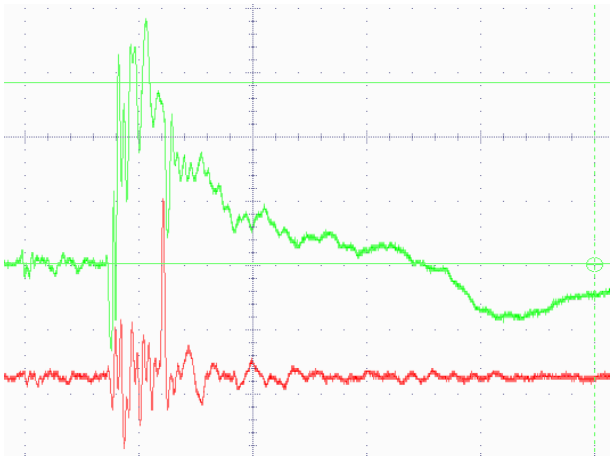
In our experiment, the UV induced flashover is under pulsed voltage. The flashover voltage of the illuminated case is lower about 8%, 11% and 21% than the unilluminated case for the first breakdown voltage, conditioned breakdown voltage and holdoff voltage respectively. The illumination of UV on the insulator decrease the flashover voltage other than increase it. The pulsed voltage and UV illumination perhaps imply a different flashover mechanism, and in order to obtain producible experiment and as lower deviations of the flashover voltage as possible, efforts are needed to minimize the effect of factors other than UV and the material.

Besides, the flashover voltage was measured for three different illuminated positions (centre of the insulator, cathode triple junction and anode triple junctions) on the insulator sample. In addition, a copper mesh was used to cover the photodiode in

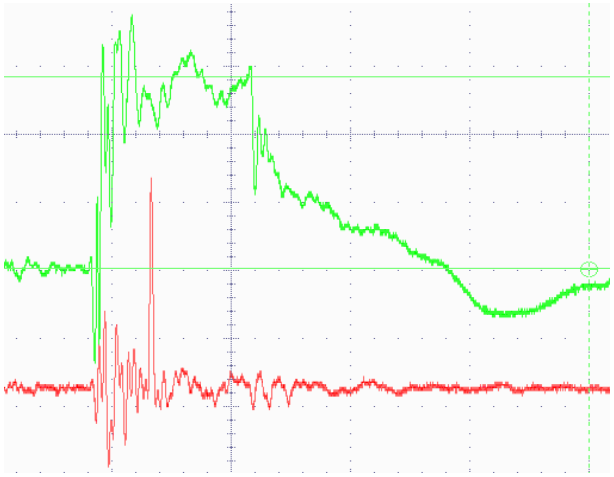
order to reduce the electromagnetic interference, otherwise the laser signal can not be distinguished. Flashover waveforms of different illuminated positions under the same voltage level (about 14.2kV) are shown in Figure 3. The insulator sample was not changed during this group of experiments. The experiment results are listed in Table 2.



(a) Centre illumination (without flashover)



(b) CTJ (cathode triple junction) illumination



(c) ATJ (anode triple junction) illumination

Figure 3: (a) , (b) and (c) are the flashover voltage signal (green) and laser signal (red) with copper mesh

Table 2: Conditioned flashover voltages of different illuminated positions

Case	Self flashover	Centre illumination	CTJ	ATJ
Conditioned flashover voltage/kV	22.3	15	<8.3	13

The conditioned flashover voltage under cathode triple junction illumination was not obtained due to the limitation of pulsed voltage system. The results show that the conditioned flashover voltages were nearly the same between centre illumination and anode illumination, but the cathode triple point illumination decreased the insulator performance a lot. Another phenomenon is that the flashover occurs immediately when the laser was illuminated on the cathode triple junction, but there exists a time delay of a few hundreds of nanoseconds when the laser was illuminated on the anode triple junction.

4 CONCLUSION

The flashover voltage of the illuminated case is lower than the unilluminated case. The flashover voltage was the lowest under cathode triple junction illumination, but nearly the same under illumination on the center of the insulator sample and anode triple junction. And the voltage drops almost at the same time when the UV laser irradiates on the cathode triple junction, but there is a time delay for the anode triple junction illumination. This indicates that flashover may initiate from cathode triple point which is in accordance with the SEEA (secondary electron emission avalanche) model, and it is more important to protect cathode triple junction to against UV illumination. As there are so many contrary results with UV induced flashover, in the future work, a systematic study of UV laser induced flashover under pulsed voltage is necessary for understanding the mechanism involved in the flashover process. In addition, some contrast experiments are needed to find out the substantial differences between dc and pulsed UV induced flashover.

5 ACKNOWLEDGMENTS

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6 REFERENCES

[1] H. C. Miller: “Surface flashover of insulators”, IEEE Transactions on Electrical Insulation, Vol. 24, No. 5, pp. 765-786, 1989

[2] C. L. Enloe and R. M. Gilgenbach: “Microscopic and macroscopic material property effects on ultraviolet-laser-induced flashover of angled insulators in vacuum”, IEEE Transactions on Plasma Science, Vol. 16, No. 3, pp. 379-389, 1988

[3] J. B. Javedani, T. L. Houck et al.: “Ultra-violet induced insulator flashover”, Power Modulator Conference 2008, Las Vegas, NV, United States, May 27 - May 30, 2008

[4] N. C. Jaitly and T. S. Sudarshan: “Novel insulator designs for superior dc hold-off in bridged vacuum gaps”, IEEE Transactions on Electrical Insulation Vol. EI-22 No. 6, pp. 801-810, 1987

[5] F. Hegeler, H. G. Krompholz et al.: “Dielectric surface flashover in a simulated low earth orbit environment”, IEEE Transactions on Plasma Science, Vol. 25, No. 2, pp. 300-305, 1997