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# Impact of Volume Breakdown on Surface Flashover in High Pressure $SF_6$

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We investigate the pulsed flashover voltage of dielectric samples at up to 4 bar $SF_6$ in the simultaneous presence of a high current (> 10 kA, ∼ 20 microsecond pulse) volume discharge nearby. The chosen distance, ∼ 7 cm, between surface and volume breakdown is consistent with conditions found in the Sandia-Z-machine type rimfire switch. For a flashover gap distance of 24 mm and a simultaneous excitation within ∼ 5 microseconds, we observe an average reduction in the flashover voltage from 164 kV to 142 kV at 3.7 bar when the volume discharge is turned on. The test setup utilizing a magnetic switching scheme operating at 320 kV and 10 kA is briefly discussed along with the breakdown properties and the spectral characterization of the volume/surface flashover discharge plasma. In general, UV light propagates relatively unattenuated for wavelengths > 160 nm in the high pressure $SF_6$ from the volume discharge to the dielectric surface, setting up conditions which are conducive to photoelectron emission from the dielectric.

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## 1. Introduction

It is possible to switch several megavolts with a gas switch based on multiple spark gaps in series in a so-called rimfire topology [1]. The typically cylindrical switch supports the voltage gradient along its cylindrical axis: in the center with alternating metal/insulating disks surrounded by a dielectric switch envelope to separate the gas switching medium from insulating liquid (gas or oil). The distance between the edge of the metal disks (where the arcs are formed during switching) and the inside of the dielectric envelope is several centimeters for a typical MV switch presently utilized in the Z-machine at Sandia National Laboratories. During switch operation, the electric field collapses between the metal disks first due to arc formation while the field at the envelope at the same axial position can still be quite high on a fast time scale. Hence, the switch envelope experiences a high electric field while subjected to the strong light emission from the volume arc, conditions conducive to surface flashover. Such flashover was observed in a rimfire switch with contiguous dielectric envelope when pushed to the extreme. This paper discusses the hypothesis that the UV emitted by a volume arc (formed between the rimfire electrodes) causes a reduction in the surface flashover hold-off field of a nearby dielectric (the envelope).

## 2. Experimental setup

A stainless steel chamber was utilized to simulate the typically pressurized environment of a rimfire switch, covering a pressure range from a $10^{-5}$ to 3.7 bar of $SF_6$.

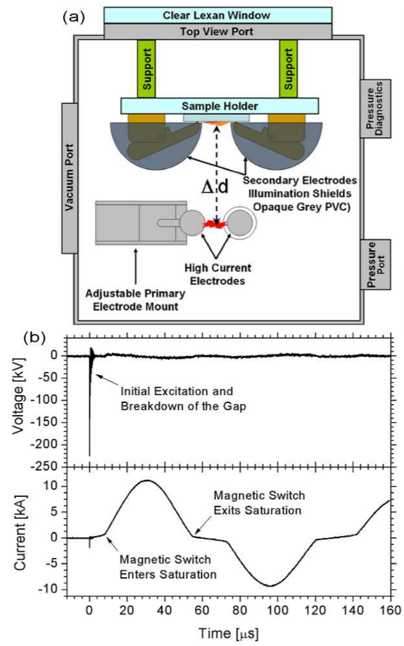


Fig. 1. (a) Side view of the chamber configured for high current discharge / surface flashover interaction testing. Diagram illustrates the relative position ($\Delta d \sim$ 7 cm) of the primary volume and secondary surface flashover gaps. (b) Typical volume breakdown waveforms at 3.7 bar of $SF_6$.

The chamber houses a primary volume gap and a secondary surface flashover gap, see Fig. 1a. This enables testing of the flashover-holdoff reducing effect of a high current volume breakdown, see Fig. 1b for a typical current wave form, in close proximity to a dielectric surface under high field stresses. The distance of ∼ 7 cm be-

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tween the primary volume gap and the secondary surface flashover gap is equivalent to the distance between the rimfire (backbone) electrodes of the rimfire switch and the dielectric envelope. A magnetic switching scheme was employed for excitation of the volume gap [2]. This produced the high voltage necessary for initiating the breakdown while still pushing kA currents. Both initial volume excitation and flashover pulses were produced by small Marx generators with output amplitude of up to 350 kV.

An opaque cover was added to the setup in order to exclude photoemission of electrons from the metallic electrodes. To further narrow down the impact of the volume arc on the surface flashover, an optical isolation and filter apparatus was available to place between the high current volume discharge gap and the secondary surface flashover gap. This enabled controlling of the illumination incident on the flashover surface (cf. Fig. 4b for flashover voltage waveform).

## 3. Results and discussion

The measured emission spectra of the volume arc lacks discrete spectral lines which makes peak identification difficult, see Fig. 2. However, the overall spectrum indicates a strong contribution in the UV region, < 350 nm. A shift in the main radiation toward the deeper UV is apparent at the higher currents, e.g. 10 kA vs. 800 A in Fig. 2b. This is important as photoemission of electrons by UV photons impacting the envelope is one of the suspected reasons that can lower the flashover voltage of the inside envelope surface. In addition, the regime below 320 nm has been identified in previous research as having a distinct effect on the spark path of flashover [3]. Utilizing a 30 $\mu$s delay between the application of the voltage to the volume gap and the surface gap, see Fig. 3a, reveals a roughly 14% reduction in flashover voltage amplitude from the no-volume discharge case.

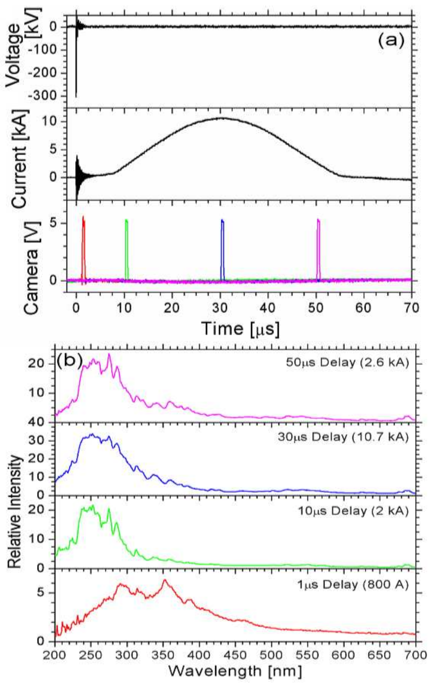


Fig. 2. (a) Typical high current volume breakdown waveforms and camera gates. (b) Optical emission spectra of volume breakdown at 2.3 bar of $SF_6$ [2].

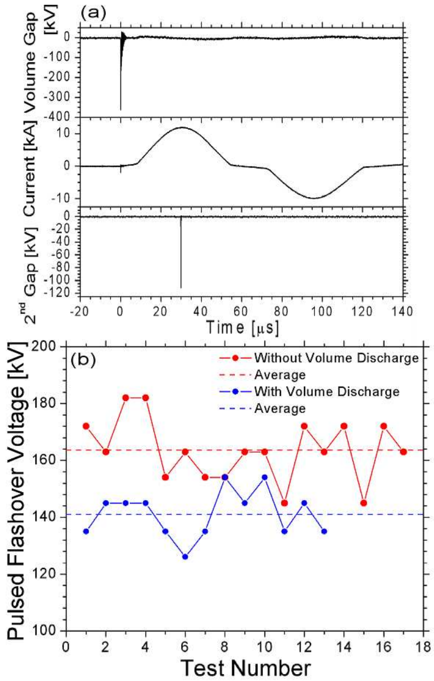


Fig. 3. (a) Voltage and current waveforms illustrating the relative timing of the high current volume gap and the secondary surface flashover gap. (b) Pulsed voltage necessary to flashover the secondary gap both with the high current volume discharge (bottom curve) and without (top curve).

To further narrow down the impact of the volume arc's spectral intensity on the flashover voltage, optical filters (useable range between 200 and 800 nm) were placed between the volume arc and the surface. Since there is little difference in the results between the filters with neutral density of 1 and 2 or the completely shielded case, see Fig. 4, one might conclude that the part of the spectrum primarily responsible for lowering the flashover voltage amplitude is below 200 nm. It should be noted in this context that UV light down to ∼ 160 nm is readily transmitted in pure $SF_6$ for distances relevant to the rimfire switch (∼ 7 cm). However, direct particle transport (ions, electrons) from the volume arc to the surface is also possible and considered a likely source of flashover reduction at the pressure and time scale involved. It is planned to conduct future experiments that utilize a highly UV transmissive $MgF_2$ window (cutoff ∼ 115 nm) as a filter between volume breakdown and the surface.

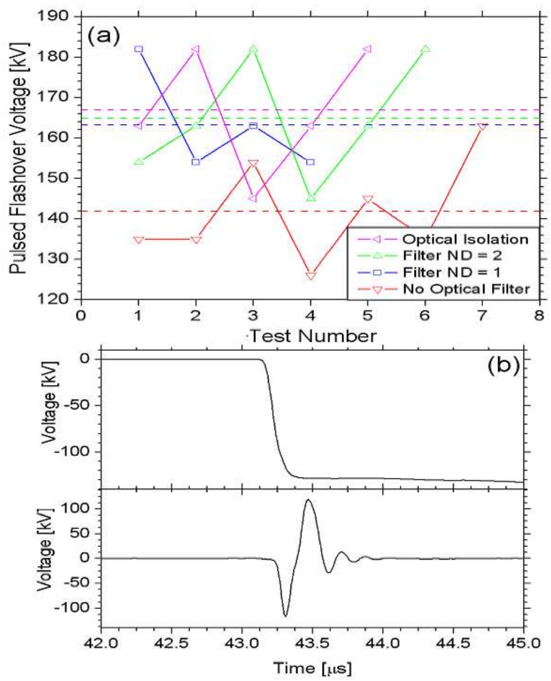


Fig. 4. (a) Flashover voltage of a 24 mm gap across Lexan with varying levels of light attenuation from a ∼ 10 kA volume discharge. The dashed lines represent the mean value for each data set. (b) Voltage waveforms measured with capacitive divider in 50 Ω transmission line; top: no flashover, bottom: flashover.

## 4. Conclusion

It was shown that a 10 kA volume arc in high pressure $SF_6$ (3.7 bar) reduces the pulsed flashover holdoff voltage of a dielectric surface on average by 15%. It is speculated that direct particle transport from the volume arc ($\mu$s time scale) to the surface is the cause for the observed reduction in flashover voltage. On faster time scales, photoemission from the dielectric due to UV radiation produced by the volume arc is also a possible cause of this reduction.

## References

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