A new approach to spark gap design is discussed. The object of this paper is to summarize the application of pulsed volume preionization of the path ahead of a propagating streamer for control of the streamer transit time. This approach to switching differs from most triggered switches in that an already propagating streamer is caused to close by command. This control is applied to construct a subnanosecond jitter, high voltage switch which operates down to 60% of its self-breakdown voltage.

This switching concept evolved from an investigation of the formative time of pressurized gas gaps; this formative time consists of an avalanche and streamer phase. The effect of preionization was considered in some detail.

Ultraviolet light incident on the gap has two primary effects: one is to provide an initiating electron for the avalanche, and the second, of interest herein, is to change the streamer velocity. The primary observations are that preionization of the gas volume changes streamer velocity by orders of magnitude. For typical gap spacings, streamer transit times are reduced to subnanoseconds. The streamer is controlled by ionizing the volume of gas ahead of a streamer by a pulse of ultraviolet light, probably through photo-detachment, thereby increasing the streamer velocity.

From the literature we glean the following concerning the effect of preionization. Streamer velocities have been reported up to $10^{10}$ cm/sec. As few as $10^3$ electrons/cm$^3$ are sufficient to radically affect the streamer velocity. Removal of these electrons has been shown to inhibit streamer propagation.

We now review the basic experimental setup and terminology used. We consider in detail the case of a Marx generator ringing up into a pulse-forming line whose voltage is applied directly across a test gap. This configuration provides a $1 - \cos wt$ waveform during the first half period before breakdown. Assuming that an avalanche is initiated at the cathode by a single electron at the instant that the field reaches its DC breakdown value, then this avalanche propagates across the gap converting to a streamer. The Raether condition is used to determine the point of avalanche streamer conversion. The streamer then transits the remainder of the gap. The nomenclature used is shown in Fig. 1.

The empirical model of point-plane breakdown developed by J. C. Martin has been extended by him using the author's early data to apply to the uniform field case. This relation is shown in Eq. 1.

$$E_{\text{eff}}^{1/6} = K_6^{-1/6}$$

$s$ is the length of the avalanche at the instant of conversion to a streamer, and $K$ is constant for a given pressure. With reference to the electron continuity equation of a later paragraph, we estimate $s = 20\alpha g$ where $\alpha g$ is the ionization coefficient evaluated at $E g$. Our data agree with this relation within 10% for $N_2$ gaps approximately 1 cm in length and pressures of 1 to 12 atmospheres. This relation is good for designing uniform field gaps and for estimating values of $s$ of protrusions of appropriate sharpness, such as needles or plasma blobs, to launch streamers.

To analyze the progress of the avalanche in more detail, the electron continuity equation is solved under the conditions set forth by Felsenthal and Proud. This nonlinear equation is numerically integrated for those time-varying applied fields, imposing the Raether condition, to determine the point of avalanche streamer conversion, $T_\text{AS}$. The distance the avalanche has progressed into the gap is determined by integrating the varying electron drift velocity. Details of this theory are presented elsewhere.

Concerning the effect of preionization, Fig. 2 shows some experimental data for a particular set of conditions. Figure 2a shows the field applied to the gap with minimal preionization, in other words, a dark gap. Figure 2b indicates the same gap but with intense quasistatic preionization. We observe that breakdown occurs at a time corresponding to the time predicted from the solution of the continuity equation for avalanche-streamer conversion. This agrees for all cases considered. The streamer has crossed the gap in a very short time in the case of relatively strong preionization.

The streamer transit time was observed to decrease with increasing initial preionization. As the preionization is varied, the time of breakdown may be varied between the limits of intense and minimal preionization. Similar data were obtained for SF$\text{g}_6$. Thus there is a "window" between $T_\text{AS}$ and $T_B$ during which breakdown can be caused by injecting a pulse of preionization. (By preionization here we mean ionizing the path ahead of the streamer.)

The limits on the window, during which the streamer may be controlled if launched from an avalanche, are evident from $a_\mu \text{ vs } E/g$ plots (Fig. 3). $t$ is the time the field exceeds its DC value, and $E g$ is the breakdown field. This curve is detailed elsewhere. Since the equations are nonlinear and a function of preionization, no unique curve exists. A family of curves is obtained for the $T_3 + T_4$ case, the streamer transit time being strongly dependent on preionization. By controlling the preionization we can select a particular curve from this family; this selection corresponds to operating in the "window" described previously.

By providing a fast rise pulse of preionization, the breakdown can be controlled anywhere within this window. At 80% of self-breakdown voltage several shots were superimposed and the jitter was unobservable, implying that it is a nanosecond or less.

It was demonstrated that the UV radiation employed for this study passes through 6 inches of water with no observable effect on the triggering characteristics; this fact is important for water dielectric machines. A fast-rise spark gap and super-radiant nitrogen laser (3371 A) have been successfully used to provide the burst of ultraviolet.

By way of summary, we have considered a uniform field and the effect of preionization on the formative time.
Of particular interest for switching is the fact that streamer transit time can be reduced to a nanosecond or less by a pulse of preionization. Furthermore, with minimal preionization higher breakdown field values are obtained than would be predicted by Felsenthal and Proud type data. We have applied this phenomenon to construct a switch which has nanosecond or less jitter. The fact that preionization can be generated by ultraviolet light implies a simple remote control scheme.

References:


