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Surface Flashover Switch**

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A TEST OF A VACUUM/DIELECTRIC SURFACE FLASHOVER SWITCH

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Abstract

A vacuum surface flashover switch is being considered for > 10 kHz operation in a 250 kV, 10 ohm, 40 ns coaxial water Blumlein. Various possible switch design are compared, and two promising ones selected for tests in the switch test facility at LLL. The initial test configurations are described.

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Introduction

The flashover of a vacuum/dielectric surface is of interest as a mechanism for high repetition rate (≥ 10 kHz) low jitter (~ 1 nsec) switching because the flashover is expected to be followed by rapid recovery of insulation strength as in the case of a pure vacuum discharge. Switches based on pure vacuum have not so far achieved the necessary low jitter, but the presence of the dielectric surface should supply a rapid triggering and breakdown mechanism and thus make ~ 1 nsec jitter possible.

Many experimenters have found that the flashover of a vacuum/dielectric surface produces a nanosecond-like transition to very low impedance with negligible pre-breakdown current. In fact, the transition time and the impedance in the "on" state are both so small that they have yet to be measured. (Consequently very little energy is deposited in the discharge or on the dielectric.) The flashover occurs at a critical field (F) that is fairly reproducible, independent of electrode spacing, and only weakly dependent on the voltage duration (t) in the range 10 nsec to 10 μ sec, $F \sim t^{-1/6}$. All of these properties make the process suitable for use in a three-electrode field-distortion switch.

In such a switch, a sharp-edged trigger electrode is at first maintained physically and electrically on an equipotential in uniform field between the electrodes to be switched. It is then pulsed to a different potential; the gross electric field is thereby increased on one side of the electrode and the local field is enhanced near its edge. In the case of the vacuum surface switch, an important aid to breakdown under trigger should be available because the breakdown field F is a strong function of the angle between the

electric field and the surface, Fig. 1, being a factor of 5-10 lower when the field accelerates electrons along and into the surface than when the electrons are accelerated away into the vacuum. It can easily be arranged that the trigger pulse change the field direction from the one in which the surface is strong to that in which it is weak, and moreover, this direction change can be made to occur in the region of greatest field enhancement.

Configurations

A number of switch configurations can be envisaged having the desired properties described above. They can differ from each other in the three ways listed below:

- 1) Trigger electrode situated in either the dielectric or the vacuum.

Both locations have possible advantages. Placing the trigger in the dielectric has the advantage that it is not required to carry the discharge current. On the other hand, in the vacuum, it can generate UV and electrons that may speed and regularize the first stages of breakdown. It has been found experimentally that UV by itself can trigger flashover of vacuum surfaces at fields well below normal safe operating levels.

It appears likely that the choice between these trigger electrode locations will determine the polarity needed for the trigger pulse, since the desired acceleration of electrons into the surface after triggering clearly requires either a positive potential on an electrode inside the dielectric or a negative potential on an electrode outside it.

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- 2) Load current flows from the discharge toward the dielectric or toward the vacuum.

In the context of the pulse-line application, the choice is between using the inside-surface of a dielectric containing vacuum (such an insulator is always required to separate the vacuum from the water), or the outside-surface of a second dielectric contained within the vacuum, Fig. 2. Which is the more convenient practically, depends on whether or how often the switch surface must be replaced.

The difference determines whether the self-magnetic field pushes the discharge onto the dielectric or into the vacuum. The first case might just possibly speed recovery, but the second may reduce insulator wear.

- 3) The trigger may be located near the cathode or near the anode.

Vacuum surface flashover is known to propagate in either direction, but the mechanisms are probably different, and this may affect the properties of the switch. A more central location for the trigger electrode is possible, but is of less interest since it requires a higher-potential trigger electrode, a larger trigger pulse for the same field effect, and the effective propagation of the discharge in both directions instead of mainly in one.

Choice of Configuration for Tests

It is not practical to test all of the eight combinations that can be made from the three pairs of conditions above. However, it does seem desirable to test both the dielectric and the vacuum locations for the trigger

electrode, since this choice may have the greatest effect. With this in mind, all eight combinations were briefly compared.

It was apparent that many cases required that the trigger electrode be held at or near the natural potential of the surface on which it lies, while in other cases it should be adequate to start with the trigger electrode at the potential of the nearest main electrode. For example, if an electrode in the vacuum near the cathode is initially at cathode potential, the sign of the field at its edge is such that electrons will be extracted (Fig. 3a) reducing voltage hold-off. An electrode in the vacuum near the anode, however, may be held at anode potential without causing emission or any other activity; its effect is to shield the anode triple-junction, Fig. 3b. Similarly, an electrode placed inside the dielectric near the cathode and at cathode potential will not degrade voltage hold-off because it shields the cathode triple-junction and increases the favorable angle between the field and the surface, Fig. 3c.

It is convenient experimentally to establish the initial trigger potential simply by connecting the trigger electrode to the nearest main electrode with a resistor, rather than by balancing it accurately at an intermediate potential. Also, the need to perform careful field calculations and possibly contour the electrode are avoided. Therefore, the cases shown in Figs. 3b and 3c have been preferred for initial tests. Note that they make it possible to test an anode-triggered and a cathode-triggered configuration and an outside and an inside surface, as well as the locations of trigger in the dielectric and the vacuum. In the present test-system the trigger pulse enters on axis, so that when the trigger

electrode is in the dielectric it is convenient to test an outside-surface switch, and when it is in the vacuum it is convenient to test an inside-surface switch. Also, it is always convenient to place the trigger electrode near ground. In this way, the experimental considerations completely determine the choices among the three options discussed above.

Note also that in the chosen configurations with the trigger electrode initially biased to the nearby main electrode, the trigger pulse is required to displace the trigger electrode toward the farther electrode. This increases the fields less than when an opposite trigger pulse is applied. While it is expected that the triggering capability will still be good and at least adequate to study recovery, if the jitter or range are marginal it may be necessary to change to a different configuration, in which trigger bias away from ground is required.

Experimental Set-up

Sketches of the test configurations are shown in Figs. 4 and 5. For convenience, both use a dielectric insert rather than the existing Blumlein interface. The axial length of both switches is about 3.2 cm. With this, it is hoped to test up to about 150 kV.

The trigger electrodes in each switch are positioned at about 6 mm from the ground end. A trigger pulse of 100 - 150 kV is available, so that the fields produced between the trigger electrode and ground greatly exceed the main field. The trigger pulse is supplied by a cable feed similar to that now in use with the low pressure gas switch.

The buried trigger electrode is cast into an epoxy cone-frustrum, Fig. 4. It is circularly symmetric, so that discharges may be created all around the

switch. For this version the Blumlein must be charged positive. A positive trigger pulse is required, which can be supplied by the trigger transformer in use on the low pressure switch. The configuration is the simpler of the two and will be built and tested first.

The second configuration has a separate trigger electrode in the vacuum. It can easily be removed and modified, as can the epoxy dielectric independently. Figure 5 shows two diametrically opposite trigger regions; an electrode with full circular symmetry may result in excessive loading of the trigger circuit by electron currents to ground. For this geometry, the Blumlein must be charged negative; for the initial tests, this may be achieved simply by triggering on the first, negative swing of the resonant transformer. This geometry requires a negative trigger pulse, which is the case being used for the low pressure switch.

Figure 1: Effect of angle on 30 ns flashover of epoxy cone

Figure 2: Use of either the existing vacuum/dielectric surface or a special insert (broken lines) as switch

Figure 3: Unbiased trigger electrodes.
 Arrows show forces on electrons.
 Forces into dielectric degrade hold-off.

Figure 4: Dielectric-cone test switch

Figure 5: Dielectric-ring test switch