Effect Of Area On Surface Flashover Voltage In Vacuum

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ABSTRACT

It is known that the breakdown voltage in a vacuum insulation system drops with an increase in linear dimension of electrodes and with an increase in the number of insulating spacers bridging the gap. Normally this is explained to be the result of the increase in the number of so-called weak links in the system. In This paper the influence of an external capacitance on the flashover voltage of an electrode gap bridged by a spacer was investigated. When a capacitor was connected inside the vacuum chamber near the discharge site in parallel with the gap, it was found that the additional capacitance lowered the breakdown voltage in a manner similar to that observed with an increase in electrode area. This advocates the energy explanation of the area effect. A larger external capacitor, far from the discharge site, had no influence on the breakdown voltage.

INTRODUCTION

It is well known that increasing the area of electrodes or the volume of insulator under stress reduces the breakdown strength of an electrode system. When the inter-electrode gap is bridged by insulating solid spacers, an increase in the number of spacers also reduces the breakdown strength of the system. This behavior is usually explained in statistical terms. An increase in the area, volume, or number of spacers will increase the probability of finding "weak links" in the system and hence increase the probability of a breakdown at low electric stress [1,2]. By a judicious selection of statistical parameters, statistical theory and experimental results can be made to agree well.

The increase in electrode area or inter-electrode volume does, however, do more than influence the probability of finding a "weak link"; it increases the electric field energy close to the breakdown site. This increase in electrostatic energy facilitates the growth of fast breakdown processes and hence increases the probability of breakdown at low stress. It has been shown that, in the case of liquid and solid insulation [3,4], the addition of extra capacitance close to the breakdown site lowers the breakdown strength to the same degree as does an equivalent increase in electrode area, yet in those experiments the electrode configuration remained fixed and hence the "weak link" distribution was constant. The variation of breakdown strength in liquids and solids therefore has a physical, rather than a statistical, origin.

In the case of vacuum insulation the situation is more complex [5]. Additional capacitance very close (within 15 cm) of the discharge site reduces the breakdown strength in the same manner as that observed in liquids and solids [3,4], but larger extra capacitance reduces the average breakdown strength even if it is far from the breakdown site. In that case the additional energy increases the electrode damage caused by each breakdown. That lowers the stress required for subsequent breakdowns. The average breakdown strength therefore falls even though the additional capacitance has no influence on the first breakdown.

It is to be expected therefore that additional capacitance will be able to lower breakdown voltages if it is either able to reinforce the growth of fast prebreakdown events or to provide extra energy to damage electrodes and hence create weak points for the initiation of subsequent breakdowns. It was the aim of the experiments reported here to discover how extra capacitance influences the surface flashover of solid insulators bridging a vacuum gap. Surface flashover

0018-9367/88/0200-43$01.00 (c) 1988 IEEE

in vacuum is a very rapid process [6]. The extra capacitance can only contribute to the development of the initiating events if it is very close to the discharge site. The discharge channel develops in gas desorbed from the insulator surface and gas evaporated from the insulator surface [7]. The development of a breakdown plasma in gas released from the insulator surface requires much less energy than the production of a plasma from the electrodes[8] therefore it is to be expected that the melting of the electrodes will be much less important in surface flashover than in the case of an unbridged vacuum gap.

EXPERIMENTAL PROCEDURE

All tests were carried out in a stainless steel vacuum chamber pumped by a rotary pump and an oil diffusion pump equipped with a liquid nitrogen trap. Vacuum was always better than 10^{-3} Pa for breakdown tests.

Test samples consisted of high-density alumina cylinders, 12.5 mm in diameter and length of either 12.5 or 7.0 mm, placed between uniform field aluminum electrodes with the central region lapped flat. The electrodes made a butt contact with the insulator with no shielding or metalizing of the junction.

Voltage was applied from a stabilized dc supply with a ripple of less than 0.01% via a current-limiting resistor of 10^8 Ω. The voltage was applied with a constant rate of rise by means of an automated system that permitted repeated testing and recording of the breakdown voltage.

Two types of capacitors were used to add extra capacitance to the electrode system: (1) C_1, a capacitor of 270 pF produced by two aluminum plates within the vacuum chamber. That capacitor could be switched in or out by means of a rotary vacuum feedthrough. The capacitor C_1 was positioned within 15 cm of the electrodes. (2) C_2, a paper-oil capacitor of 0.01 μF external to the vacuum chamber.

RESULTS

Fig. 1 shows the influence of the vacuum insulated capacitor, close to the spacer, on the discharge voltage U. For these tests the spacer length was limited

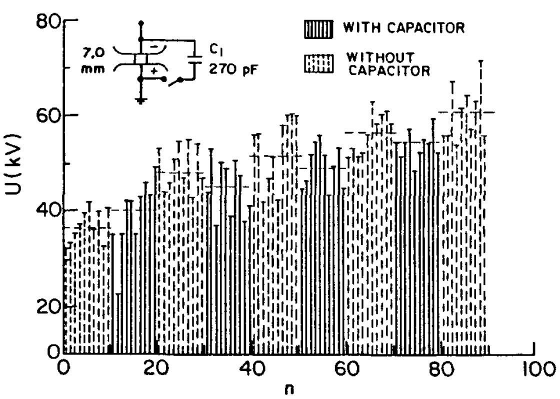

Fig. 1: Flashover voltage U vs number of test n, with and without C_1.

to 7.0 mm by the flashover of the supports for the vacuum capacitor. The general upward trend of the voltage with repeated tests is the normal conditioning process. It can be seen that the connection of C_1 in parallel with the gap produces a drop in the first breakdown after connection and that, after the initial sharp rise in breakdown voltage due to conditioning, the addition of extra capacitance reduces the average breakdown strength of the gap. The degree of reduction is similar to that found by increasing the electrode area sufficiently to add 270 pF to the gap capacitance [2].

Fig. 2 shows the effect of the 0.01 μ F capacitor external to the vacuum chamber. No distinct influence of the extra capacitor can be found. There is a general upward trend in the breakdown voltage due to conditioning, but the addition of the capacitance does not produce a drop in the breakdown voltage.

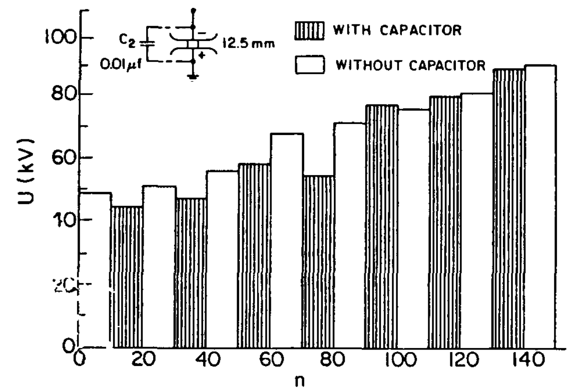

Fig. 2: Flashover voltage U vs number of test n, with and without C_2.

DISCUSSION

It has been previously shown that the development of surface flashover in vacuum involves a first stage lasting <1 ns. Extra capacitance, vacuum insulated, within 15 cm of the insulator can contribute energy to that process and hence maintain the electric field necessary to drive and release the charge carriers. For that reason, with the extra capacitance C_1 close to the spacer, the breakdown can occur at lower voltage than with the electrodes alone.

When a paper-oil capacitor is connected external to the chamber, the inductance of the circuit and the time dependence of the polarization of the capacitor dielectric slow the energy release to the discharge site on the spacer. Microseconds are needed for the energy transfer and therefore the external capacitor has no influence on the initial development of the flashover. With surface flashover, unlike the case of an unbridged vacuum gap [5] electrode damage does not play a major role in the breakdown, and therefore the slow acting external capacitance does not influence the flashover voltage.

CONCLUSIONS

The experiments show that, in common with liquid [3] and solid [4] insulation, surface flashover in vacuum occurs at a lower voltage when extra capacitance is located close to the spacer. This effect is the same as would be produced by increasing the electrode area. The absence of any influence of a slow external capacitance illustrates that electrode damage does not play a significant role in surface flashover in vacuum.

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Manuscript was received on 28 June 1986, in revised form 7 April 1987.

This paper was presented at the 12th International Symposium on Discharges and Electrical Insulation in Vacuum, held in Israel from 22 to 25 September 1986.