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AUTHOR(S) J. D. Smith, D. J. Kahalan, E. M. Honig, R. E. Montoya,
L. A. Rosocha, G. R. Allen, and W. F. Aaron III

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Los Alamos National Laboratory
Los Alamos, New Mexico 87545

IMPROVED VACUUM SURFACE FLASHOVER PERFORMANCE OF POLYMER INSULATORS BY THE USE OF UNIQUE TRIPLE JUNCTION DESIGNS*

J. D. Smith, D. J. Kahanian, E. M. Honig,
R. E. Montoya, L. A. Rosocha, and G. R. Allen
Los Alamos National Laboratory
Pulsed Power Systems, CLS-7, MS-E525
Los Alamos, NM 87545

W. F. Aaron III
Texas Tech University
Pulsed Power Laboratories
Physics Department, P.O. Box 4180
Lubbock, TX 79409

Abstract

Previous research and theories about surface flashover in vacuum indicate that the triple junction region plays a critical role in the insulator flashover process. To attempt to improve upon the performance of the standard 45 degree frustum insulator, three different insulator geometries with modified triple junction regions were investigated. Two samples of each geometry, each 2 cm thick, were tested to obtain the flashover voltage levels in a low 10^{-5} Torr vacuum using a 1.2-microsecond risetime voltage pulse. Each sample was tested five times with 20 shots per test for a total of 200 shots per geometry.

Test results and comparisons of the flashover voltage levels for the four geometries are presented. One geometry showed an improvement in flashover voltage of about 40% over the standard 45-degree frustum. It also showed significantly less susceptibility to low voltage flashover due to surface damage, suggesting a correlation between surface damage and the development of conductive paths along the surface.

Introduction

The triple junction region plays an important part in the surface flashover process [1]. Most theories and experimental evidence indicate that the surface flashover voltage level of an insulator is dependent on the electric field strength at the cathode triple junction region. Our initial goal was to see if certain geometries would lead to a lower cathode triple junction field, resulting in a higher hold-off voltage. Four geometries, shown in Fig. 1, were chosen to investigate this possibility.

The first geometry consisted of the geometry investigated and applied 45 degree frustum. The second geometry consisted of a special design that would lower the field at the triple junction region. The third geometry is a modification of the second geometry. And the fourth geometry added an embedded conductor to further lower the field at the triple junction region.

Figure 2 shows a typical secondary electron emission coefficient curve for an insulator. Electrons with energy greater than E_{max} impacting the insulator surface will cause the insulator negatively charged at the triple junction. This charge will partially cancel the field at the triple junction region.

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near-surface bulk charging. Referring to Fig. 3, if charging of the insulator surface across from the triple junction region occurs, then a lowering of the electric field at the triple junction region would occur.

Figure 1. Side view of standard 45 degree frustum and three special insulator designs

Figure 2. A typical secondary electron emission coefficient curve for an insulator

Figure 3. First special design sample showing the triple junction location and the region of negative charge buildup.

Figure 4 shows electric field and equipotential line plots for the four geometries. These plots were created using a finite element analysis code on a Sun computer. Analysis of these plots indicate that the electric field

impacting the region opposite of the triple junction should have sufficient energy, greater than A_2 , to cause a negative charge buildup. Whether or not this charge buildup will be sufficient to noticeably influence the surface flashover voltage depends on a few factors. First, there is a charge leakage rate that is dependent on the amount of charge buildup, material, and local electric fields. Second, there is a deposition rate that depends on the holdoff voltage of the insulator and the shape, voltage, and repetition rate of the pulses applied. The deposition rate is also dependent on the field at the triple junction, material, and the energy of the electrons impacting the surface.

Standard 45 Degree Frustum

First Special Design

Second Special Design

Embedded Conductor Design

Figure 4. Electric field and equal potential lines plotted for the four geometries.

Three possible outcomes of surface charging are possible. First, the charge buildup is limited by the leakage current deposition rate. Second, the electric field at the triple junction is so low when compared to the strength of the local electric field at the triple junction, hence, the charge buildup is limited. The third possibility is that a local electric field at the triple junction is created by the electric field only component of the overall electric field, which is the sum of the electric field of the insulator and the electric field of the charge buildup. A low electric field at the triple junction would result in a low deposition rate of the negative charge at A_2 . The third possibility of the charge buildup is that a substantial radial component of the electric field is present.

Referring to Fig. 4, the three special designs have the added advantage of possibly having a radial component of the electric field in

the recessed region of the insulator. How well this process works to increase the flashover voltage level is probably dependent on pulse duration. All four geometries have the added holdoff voltage advantage of the 45-degree sloping outer profile in comparison to a cylinder [2]. Depending on the amount of charge buildup, the first two special geometries could also provide an extra radial component of the electric field that would drive electrons away from this outer profile surface. The embedded conductor design is, in a sense, an extreme case of the first special design. It has a substantial radial component to drive electrons away from the 45 degree sloping surface.

Experimental Setup and Procedure

The ability of each design to effectively prevent the occurrence of surface flashover was tested through experimentation performed at the Bushing Test Facility at Los Alamos National Laboratory [3]. The 11 stage Marx bank has the 81 nF, 100 kV capacitor per stage and can be charged to a maximum energy of 4.4 kJ by a 100 kV, 18 mA DC power supply. The Marx bank is capable of providing pulses with voltages up to 1 MV.

Samples were tested between stainless steel electrodes formed to a Bruce profile. These Bruce profile electrodes provide a fairly uniform field in a gap ranging from 0 to 16 cm.

All four geometries were originally manufactured out of Ilexan, a General Electric polycarbonate. The second manufacturing of the embedded conductor design used an acrylic resin.

Two samples of each geometry were manufactured, with the exception of the second special design in which four were created. Two samples of each embedded conductor type were created. All designs were machined to be 1 cm high and, at most, 10 cm in diameter.

The first manufacturing process for the embedded conductor sample involved cutting two pieces of Ilexan and painting a thin conducting film 50% silver by weight on the top surface of one of the pieces. A small copper wire surrounded the edge of the film to prevent high local fields. Methylene chloride was applied to the bottom of one of the pieces and the remaining Ilexan surface on the top of the other piece to dissolve the Ilexan. The pieces were then firmly pressed together and allowed to dry. The second manufacturing process for the embedded conductor sample involved cutting a small copper wire to be in an acrylic resin. After the resin had hardened, the acrylic was removed to the desired geometry.

The electrodes were polished with very fine 1000 grit paper before each test to remove scratches polished by 1500 grit. The electrodes were then cleaned with fine sandpaper with 1000 grit paper to remove any film left by the fine sandpaper.

Each sample was prepared before testing. Waxes and oil were removed from the top of the samples were removed by washing the sides of the insulator samples with 1000 grit sandpaper to be as flat as possible. The sides of the samples were sanded with 1000 grit sandpaper to ensure that the samples made a tight fit with the electrodes. The samples were then cleaned in distilled water in an ultrasonic cleaner for several minutes. Next, using rubbing alcohol, the top of the samples were

cleaned with 1000 grit paper. The samples were then cleaned with 1000 grit paper.

* brush, recleaned, blown dry, and placed between the Bruce profile electrodes. Finally, dry air was used to blow stray dust particles away from the sample and electrodes.

The vacuum chamber was sealed and allowed to pump down overnight (approximately 16 hours) to a pressure of about 1×10^{-5} torr. The vacuum system consists of two 12-inch, cold-trapped diffusion pumps and a roughing pump system.

For a given test, the sample was pulsed at 10-minute intervals for, at most, 20 pulses. The 10 minute delay was included to allow for surface charge redistribution on the sample. A 1.2 μ s risetime (10%-90%) pulse was used, and the Marx Bank was charged to a voltage which insured that the sample always broke down on the rise of the pulse.

The voltage waveform for each shot was recorded by a digital oscilloscope. The flashover voltages, corresponding to the maximum negative voltages recorded (negative polarity), were calculated by a max/min program incorporated into the oscilloscope. This data was recorded for statistical analysis and graphed on a Macintosh II computer.

Results

Due to the nature of the flashover phenomena, the statistical spread of most flashover data is large. For this reason, a statistical approach of obtaining a large amount of data and averaging that data in order to see trends was chosen. All error bars represent the standard deviation of the mean, which is defined as the standard deviation divided by the square root of the number of events. The standard deviation of the mean signifies an error in the estimate of the average.

The original embedded conductor design broke down at low voltages because of a poor bond between the two adjoining pieces of hexan. The improved embedded conductor design, made by pasting the conductor in acrylic, failed due to bulk breakdown near the edge of the embedded conductor. Both samples of both designs failed in the first shot. Therefore, the voltage results are of little value in comparison to the results of the other geometries and will not be presented.

Table 1
Average Flashover Voltages of Samples

KV	Standard 45 Degree Frustum	First Special Design	Second Special Design
Average First	324 $\pm$ 34 (10.5)	296 $\pm$ 31 (10.5)	327 $\pm$ 34 (10.5)
Average Highest	412 $\pm$ 38 (11.4)	357 $\pm$ 34 (11.4)	441 $\pm$ 31 (11.4)
Average Lowest	276 $\pm$ 41 (10.5)	204 $\pm$ 31 (10.5)	297 $\pm$ 34 (10.5)
Average	334 $\pm$ 37 (10.5)	284 $\pm$ 31 (10.5)	355 $\pm$ 34 (10.5)

Table 1 summarizes the results of the 45 degree frustum, the first special design, and the second special design tests. The average first, highest, lowest, and average flashover

values have been calculated from ten different tests for each design. Each test consisted of 20 pulses, and thus, the grand average is calculated from 200 flashover voltages.

The data in Table 1 is graphically shown below in Fig. 5. The shot by shot average of the ten samples for each of the three geometries is presented in Fig. 6.

Figure 5 Average flashover voltages of the three samples.

Figure 6 The shot by shot flashover voltage average of ten samples for each geometry. Every point and corresponding error bar are compiled from ten flashover events.

Discussion and Conclusions

The grand average first low voltage of the first special design is 10 percent higher than standard 45 degree frustum, and the design was capable of withstanding higher flashover voltages (highest first voltage of 441 KV) than standard 45 degree frustum. In the case of the first special design, surface flashover at low voltages occurred due to the poor bond between the two adjoining pieces of hexan.

As determined by photographs of the samples after a flashover, the first low flashover voltage of the first special design was due to the poor bond of the insulator, grazed by a sharp tip of the electrode. The tip of the electrode grazed the insulator, and the flashover occurred at the point of contact. The sharp tip of the electrode was not removed, and the flashover occurred at the point of contact. The sharp tip of the electrode was not removed, and the flashover occurred at the point of contact. The sharp tip of the electrode was not removed, and the flashover occurred at the point of contact.

smooth surface to develop, from flashover events, continuous carbon paths from the cathode to the anode.

Another interesting characteristic of this design was the occurrence of bulk breakdown. Four samples were needed for this design to obtain ten complete runs of surface flashover voltages. Two of the samples failed due to bulk breakdown during their third test run while one sample exhibited bulk breakdown during the second test run. In each case, bulk breakdown began at an area located in the recessed upper surface of the sample and continued directly through the material to the anode.

Bulk breakdown for 1 cm of Lexan should occur well above the test voltage applied. It is possible that the insulator accumulated a negative surface and bulk charge which effectively reduced the thickness of the insulator in that region. This is evidenced by the fourth sample which survived five complete runs without bulk breakdown but showed internal brown discoloration which is characteristic of charge stress.

Although the original research goal of detecting an increase in the surface flashover voltage due to a charge build-up in the upper portion of the recessed surface was not directly obtained, it still may be a viable process, and interesting results governing the behavior of the second special design was obtained.

The samples of the embedded conductor design which were fabricated did not perform well, however, the electric field plots indicate that the embedded conductor produces an extremely low field at the triple junction. Thus, if a more reliable design is developed, with higher hold-off voltages should be attained.

The separating processes of tearing and conditioning can produce the coating holdoff values for an insulator. The tearing of an insulator is evidenced by definite carbon parts on the insulator's surface. The Joule heating from pre-breakdown currents which flow along the carbon parts results in raising the rate of gas desorption and ultimately increases the probability of surface flashover. However, large scale "healing" by a flash of 100,000 volts or which subsequent flashovers occur on smaller insulators, which cause the Al₂O₃ film to be built up again.

[illegible]

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11. R. Hawley, "Solid Insulators in Vacuum: A Review," *Vacuum*, 11, 18, N. 1, 1964, pp. 131-9.

21. A. S. Pillai and E. Barker, "Relative Flashover of Insulator Strings," *IEE Trans., Vol. PAS-94*, pp. 1074-1079, 1974.

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