3D ELECTROSTATIC MODELING OF AN EXTENDED LIFETIME, 100pps, 500kV, LOW JITTER TRIGATRON

ABSTRACT

Two dimensional electrostatic modeling techniques have previously been used to aid the design of a high voltage, low jitter trigatron spark gap. Areas of high Electric field stress could be identified at an early stage of the design process and modified, ensuring optimum performance and lifetime of the spark gap switch. This paper describes the extension of the modelling technique using a three dimensional analysis boundary element method program to design a switch with a predicted lifetime of 10^6 shots, a single sided jitter of 1ns and an operating voltage of 500kV.

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Abstract

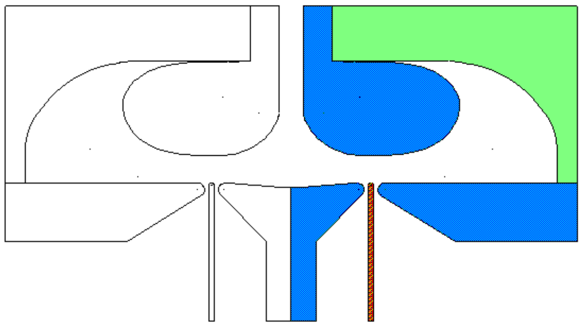
Two dimensional electrostatic modeling techniques have previously been used to aid the design of a high voltage, low jitter trigatron spark gap. Areas of high Electric field stress could be identified at an early stage of the design process and modified, ensuring optimum performance and lifetime of the spark gap switch. This paper describes the extension of the modelling technique using a three dimensional analysis boundary element method program to design a switch with a predicted lifetime of 10^6 shots, a single sided jitter of 1ns and an operating voltage of 500kV.

The use of three dimensional electrostatic analysis has enabled a complete categorization of the trigatron to be carried out. This has included the effect of space charge in the switching media and surface charge on the insulators (to simulate repetitive switch operation). Further investigations into the effect of trigger pin diameter, the proximity of this pin to the adjacent earth electrode, the earthed electrode profile, the high voltage electrode profile and the position of the trigger pin were also made. The use of 3D analysis enabled capacitance and inductance estimations to be made which could influence the performance of the switching system. Electrode trajectories were also investigated in order to ensure that the optimum switch design had been chosen.

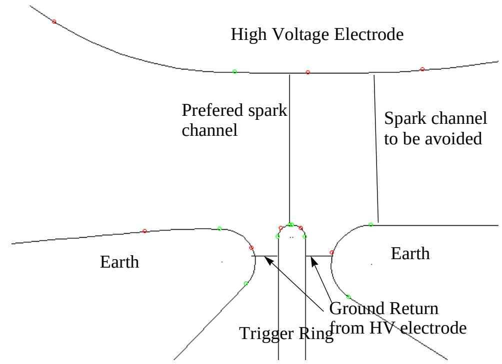
The above procedure has led to the production and testing of an extended lifetime, sub-nanosecond jitter, 500kV triggered switch which has been operated successfully at repetition rates of up to 100pps.

Introduction

A cross-section diagram of the switch prior to any modification as a result of the analysis is shown in Fig.1. The electrodes are made from stainless steel and the main gap spacing was permanently set to 7mm. The trigger ring is 40mm in diameter and the trigger gap is variable depending upon the thickness of the trigger ring electrode. Fig.2 shows further detail of the electrode profiles in the region where the trigger ring enters the main gap with the two most likely spark channel paths indicated. The first of these is from the upper electrode to trigger ring to earth electrode and is the preferred spark path for low jitter operation[2]. The second is from the upper electrode to the earth electrode.



Schematic of Extended Lifetime Trigatron Spark Gap
Fig.1



Trigger ring and adjacent electrode profiles
Fig.2

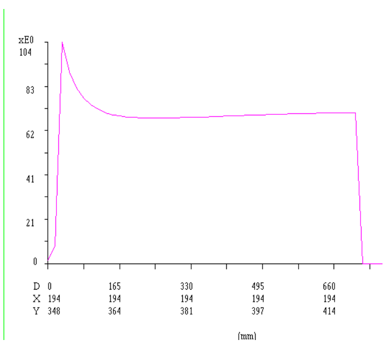
The effect of the vertical position of the trigger ring relative to the earth electrode and the thickness of the trigger ring upon the local E-field has been investigated. An alternative trigatron design, based on the average E-field in the main gap and trigger gap is also discussed and compared with the field distortion design which has been described previously [3].

The Effect of Trigger Pin Height Above the Earth Electrode

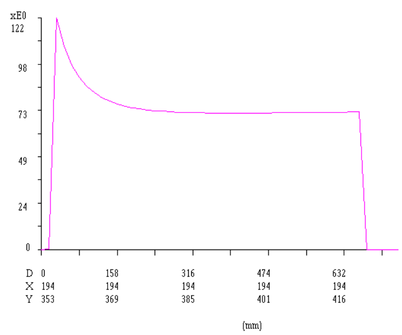
When the trigger voltage is applied, a certain degree of field enhancement must occur to ensure that a streamer channel will form between the trigger ring tip and the upper electrode. This will ensure that the main gap will break down first, followed by the trigger gap. This spark channel path generates a faster closing time and a lower jitter in the delay time[2]. However, if the trigger ring protrudes into the main gap too far, the field distortion caused by the trigger ring on application of the main gap voltage may cause the switch to fail under pulsed charged operation before the arrival of the trigger pulse. Under these conditions, the closing time and the jitter can be undesirably large.

If the degree of field enhancement is not high enough at the trigger ring tip when the trigger voltage is applied, a trigger voltage of greater magnitude would normally be required to initiate rapid closure of the switch with a suitably low jitter (ring below earth level). With the ring below the earth level, there is also a risk that closure may occur between the upper electrode and the earth electrode directly, as the electric field between the upper and earth electrodes may be comparable to the field between the upper electrode and the trigger ring.

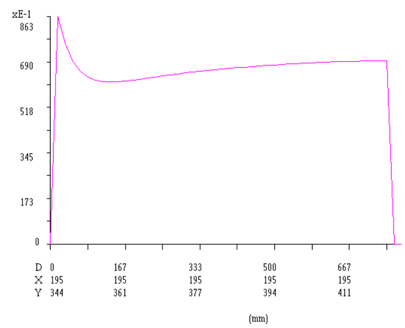
In an attempt to optimise the vertical position of the trigger ring relative to the earth electrode, the E-field along the preferred spark channel path was plotted using electrostatic analysis and the resulting E-field magnitude graphs are shown in Figs.3, 4 and 5 for the trigger ring flush with the earth electrode, 5mm below the flush level and 5mm above the flush level. All plots are for a main gap voltage of 500kV with no trigger voltage applied. The trigger ring thickness was 1.2mm with a 0.6mm radiused edge. The horizontal trigger gap spacing was 1mm. From Fig.5 it can be seen that the degree of field distortion with the trigger ring at 0.5mm below flush with the earth electrode provides a compromise between the required field distortion at the trigger ring rip for fast closure initiation and low jitter, and minimisation of the average main gap electric field for operation at voltages of 500kV. If the average E-field across the main gap is greater than about 70kV/mm the probability of unwanted self breakdown is increased. The theoretical breakdown field for 8 bar in SF_6 is ≈72kV/mm but this could not be achieved over the full gap due to the drop off in the rate of increase of dielectric strength with pressure for SF_6 at pressures greater than about 5 bar. It was therefore decided to keep the average electric field across the main gap at less than 70kV/mm to minimise the risk of self breakdown. Similarly, although a very high degree of field distortion in the trigger ring tip region is desired to initiate immediate inception and therefore to reduce jitter, the peak value must be kept below a level which would result in pre-triggering of the gap. The average field in both Figs.3 & 4 is greater than 70kV/mm (71 & 73 respectively) and the peak field is greater than 100kV/mm (104 & 122 respectively). The values for Fig.5 of 67kV/mm average and 86kV/mm peak were thought to produce a compromise between the enhanced field required to reduce jitter and the average field required to prevent self breakdown.



E-field with 1.2mm trigger ring 0mm from ground & 7mm gap
Fig.3



E-field with 1.2mm trigger ring 0.5mm above ground & 7mm gap
Fig.4

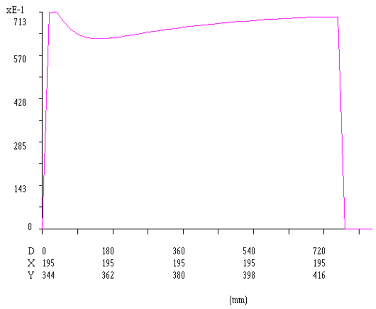


E-field with 1.2mm trigger ring 0.5mm below ground & 7mm gap
Fig.5

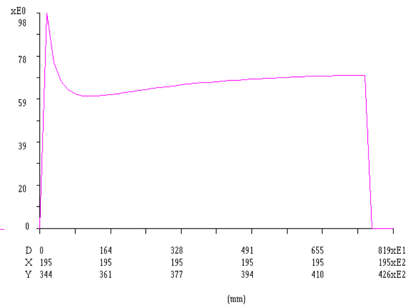
The Effect of Trigger Ring Thickness

The effect of varying the trigger ring thickness on the local electric field distribution was considered in the design as this will also have an effect on the lifetime of the trigatron. This was carried out for the optimised ring position of 0.5mm below the earth flush level. In general, the thicker the trigger electrode, the longer the shot life of the trigatron. However if the trigger ring is made too thick, the degree of electric field enhancement at the trigger ring edge may not be high enough for good trigatron performance. The electric field distribution along the path of the preferred spark channel (Fig.2) was calculated for three thickness' of trigger ring, which were 0.6mm, 1.2mm and 1.8mm. This range provides a good indication as to the effect of changing the thickness while keeping the other parameters constant. There was no applied voltage on the trigger ring for this analysis.

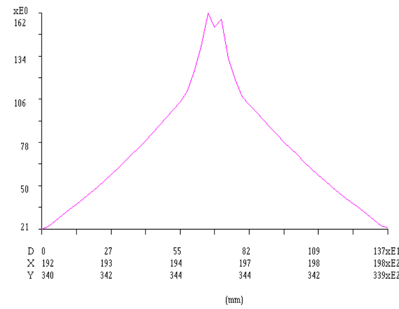
The electric field distribution observed for a trigger ring thickness of 0.6mm (Fig7) indicates that this thickness of trigger ring should generate desirably low jitter trigatron operation. Fig 7 also indicates that the enhancement caused by the trigger ring edge is high enough (98kV/mm) to ensure rapid closure after the application of the trigger voltage, and is also localised around the edge of the trigger ring. This ensures that the presence of the trigger ring does not significantly affect the average E-field in the main gap, and operation at 500kV should still be achievable for a gas pressure of about 8 bar. The high peak field may result in the occasional self breakdown and if this is unacceptable, a more conservative design must be used.



E-field on breakdown path for 1.8mm thick ring
Fig.6



E-field on breakdown path for 0.6mm thick ring
Fig.7



E-field on trigger ring for 0.6 mm diameter ring
Fig.8

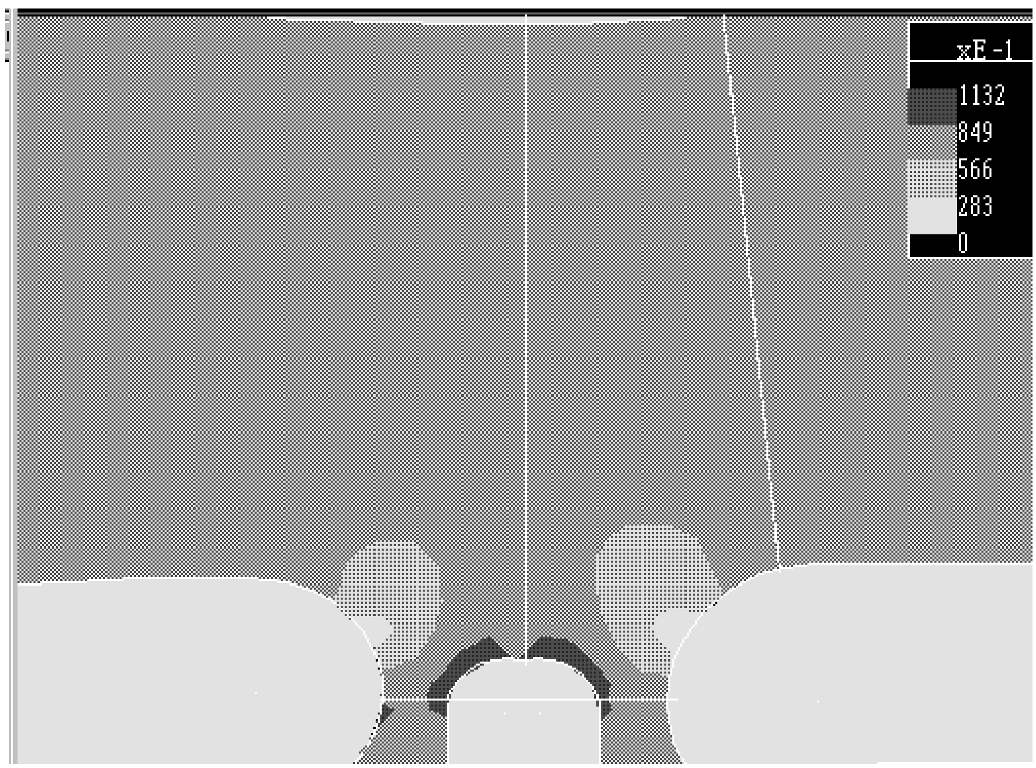


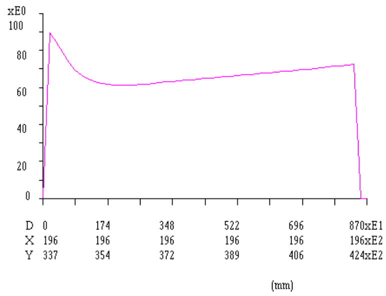
Fig. 9 : E-field distribution 65kV trigger pulse -500kV main gap voltage

A trigger ring thickness of 0.6mm would be appropriate for a device which has an expected life of ~10^5 shots[3]. However, for a longer lifetime device, a thicker trigger ring would have to be employed. For this reason the diameter of 1.2mm will be used in the extended lifetime designs. However for applications which do not require such long lifetimes and where a number of self breakdowns could be tolerated, a narrower thickness ring should be considered. The manufacturing accuracy of such a design should also be considered before this approach is followed.

Trigatron Design Based on Equivalent Average Electric Fields in the Main Gap and the Trigger Gap

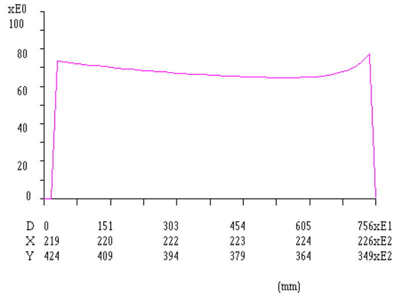
Previous investigations into triggered spark gaps[4] have considered the average electric field in both the main gap and the trigger gap. It is thought that by making the average electric field equal in both gaps would result in simultaneous initiation and development resulting in a rapid closure, low jitter device. This may be possible if both gaps were uniform and discharge initiation could be achieved simultaneously. However by the nature of trigatron design, there will be an unavoidable field distortion in the region of the trigger tip and it may be that the actual profile of the electric field should be made similar in both the main gap and the trigger gap. Since the breakdown mechanism is related to both the applied E-field and the conductor surface area / profile, the main gap and the trigger gap may not have to have identical E-field profiles. The relationship for simultaneous closure can be based on a product relation which compares the field and the critical volume. This would mean that because the area of the trigger ring presented to the upper electrode is relatively small, the applied E-field would have to be proportionally higher to initiate switch closure. Similarly the area of the trigger ring presented to the adjacent earth electrode is relatively large and the required E-field for closure would be proportionately low.

A number of iterations of trigger ring thickness, earth electrode profile and charging and/or trigger voltage were carried out until the configuration shown in the E-field map of Fig 9 was established. The analysis for this case was carried out for an applied trigger voltage of 65kV and a main gap voltage of -500kV. Also examined was the case for no applied trigger voltage which enabled both the pre-breakdown and breakdown E-field to be compared. It was important to ensure that the geometry was optimised for both cases otherwise the trigatron may close prior to the application of or inception from the trigger voltage. The level of field distortion for this design is not as high as was observed in the previous geometry (Figs.1 & 2) and therefore requires a higher trigger voltage for low jitter closure. Fig.10 shows the field along the preferred breakdown path with a 65kV trigger pulse applied (peak value 89kV/mm, average 65kV/mm) and Fig.13 shows the same analysis with 0V on the trigger (peak 45kV/mm, average 60kV/mm). The other relevant breakdown paths (hv electrode - ground) are shown in Figs.11 & 14 (with and without 65kV trigger pulse respectively) and trigger - ground in Figs.12 & 15 (with and without 65kV trigger pulse respectively). This type of geometry will be studied and its performance compared to the previous design, shown in Fig 2, in order to establish the merits of this design approach.



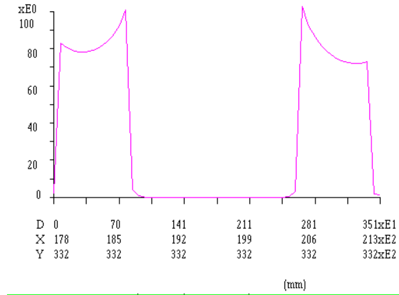
E-Field on breakdown path
(via ring)

Fig. 10



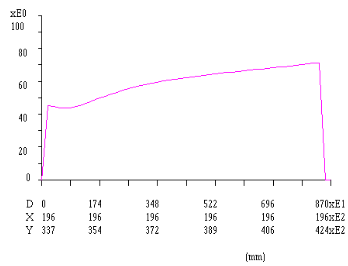
E-Field on hv to ground path
For 65kV on trigger ring
(after initiation)

Fig.11



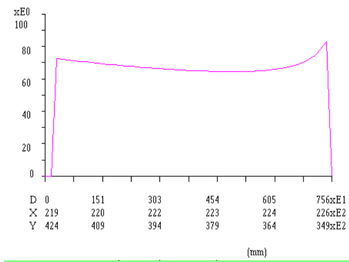
E-Field on ring - ground path

Fig.12



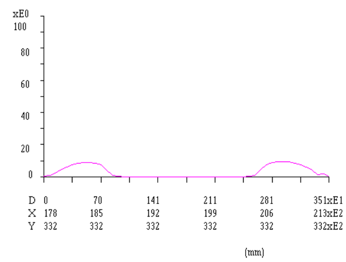
E-Field on breakdown path
(via ring)

Fig.13



E-Field on hv to ground path
For 0V on trigger ring
(before initiation)

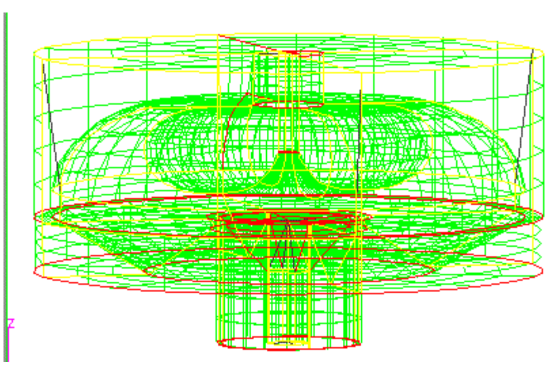
Fig.14



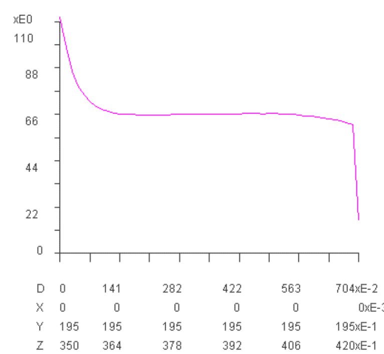
E-Field on ring - ground path

Fig.15

A comparative analysis of the extended lifetime trigatron was carried out using a 3D analysis BEM program. The results from this were compared with those produced by the 2D analysis and the relative accuracy was estimated. This will give the option of introducing 3D effects like space charge and corona sources, enabling a fuller understanding of the trigatron design to be gained in future. The elemental structure and trigatron geometry for the 3D analysis is shown in Fig.16.



3D representation of extended trigatron spark gap
Fig.16



E-field along proposed breakdown path ring 0mm
Fig.17

The average E-field away from the trigger ring region is 67kV/mm with the peak at the ring reaching 110kV/mm (as shown in Fig.17). When this is compared with Fig.3 which is the same analysis for the 2D program Electro this gives a relative error of 5% which is acceptable for this level of analysis. If a more accurate solution is required the elemental structure in the relevant region can be increased to compensate for this. Further investigations are intended using the 3D model to identify the influence of space charge and corona sources on trigatron performance.

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