PERFORMANCE OF PLASMA CLOSING SWITCHES FILLED WITH AIR, NITROGEN AND A NITROGEN/OXYGEN MIXTURE

M. HOGG, I. TIMOSHKIN, S. MACGREGOR, M. GIVEN, M. WILSON, T. WANG

University of Strathclyde, Glasgow
204 George Street, G1 1XW
United Kingdom
michael.hogg@strath.ac.uk

ABSTRACT

This paper presents an experimental investigation into operation of a triggered, two electrode switch energised with a HV impulses superimposed over a DC charging voltage. A sphere-sphere topology with an electrode separation of 2 mm was DC energised to 6 kV, 7 kV and 8 kV and triggering impulses of varying *dV/dt* have been used. Breakdown voltage, time delay to breakdown and jitter have been measured for air, nitrogen and a 60% nitrogen/40% oxygen mixture. It is shown that higher *dV/dt* and higher DC energisation provide more stable and shorter time delays to breakdown.

1. INTRODUCTION

Plasma closing switches are widely used in the power and pulsed power industry as they can operate at high voltage and high current with fast closing times and low jitter. In recent times there has been a renewed interest in plasma closing switches with low jitter and low inductance filled with environmentally friendly gases, [1].

A gas which is traditionally used in high voltage and pulsed power engineering as an insulating or switching medium, sulphur hexafluoride (SF_6), is known to be a greenhouse gas, [2]. Also, SF_6 gas is expensive to source and to reclaim. This research focuses on identifying environmentally friendly, low cost gases to replace sulphur hexafluoride in plasma closing switches without detrimental effects to their performance. Many pulsed power systems which include plasma closing switches such as linear transformer drivers require rapid current rise after their closure. Therefore, inductance of the switch and plasma channel should be minimised, [1].

Plasma closing switches can be subdivided according to their triggering modes of operation: self-breakdown, field distortion switches, trigatrons and laser triggered switches.

Simplest self-breakdown topology only requires two electrodes, this switch operates when the breakdown strength of the gas inside the switch is exceeded. The breakdown strength can be exceeded by different methods such as: reducing the inter-electrode gap by moving electrodes or by reducing the gas pressure inside the switch. Reducing the gas pressure to trigger a self-closing switch is commonly used to trigger pulsed power generators such as Marx generators.

Field distortion triggering requires a more complex circuit and field distortion switch topology is more complex as compared with a single gap self breakdown switch. A third floating trigger electrode is positioned between the high tension and ground electrodes along the equipotential surfaces. A DC energised switch is triggered when a trigger pulse is applied to the trigger electrode, increasing the local field strength in the region on one of the primary electrodes, initiating a breakdown. This form of triggering is used in large pulsed generators such as linear transformer drivers where switches are charged to ±100kV DC and as many as 100 000 switches are triggered at the same time, [1].

Trigatron switches also incorporate a third, trigger electrode and a triggering circuitry. A complete breakdown (switch closure) in a trigatron switch is initiated by creating a plasma channel between the triggering electrode and one of the primary electrodes. This initial plasma generates charge particles and UV photons which lead to the switch closure (complete breakdown between the main electrodes). Trigatrons can operate in repetitive modes and are often used for high repetition triggering applications such as pulsed UV lamps, [3].

In laser triggered switches a laser impulse is used to form a plasma channel between two electrodes. For example, UV laser triggering is used for the 6MV multi-stage switch at Sandia National Laboratories, [4].

Each of the triggering mechanisms discussed have advantages and disadvantages. Laser triggering is very complex and costly and as such is not used often, multi-electrode switches complicate the switch adding inductance and creating issues with electrode erosion decreasing switch life time and performance. The self-breakdown switches are low effective devices which in main cases do not provide required degree of controllability over the switching operation.

This paper investigates operation characteristics of a DC energised two electrode switch which can be triggered by superimposing a high voltage impulse on top of the DC stress to force the switch to close. In this work different environmentally friendly gases were used as switching media: air, nitrogen and a nitrogen/oxygen mixture (60%/40%) with a view to replace the SF_6 in plasma closing operations using the superimposed switching mechanism.

2. EXPERIMENT

The switch which is consists of two spherical brass electrodes (9.5 mm diameter) is DC stressed to a voltage which is lower than the static breakdown threshold. Then a high voltage impulse of the same (negative) polarity is superimposed on the DC sterss, resulting in switch closure by creating an overvoltage.

The switch was filled with air, nitrogen and a nitrogen/oxygen (60%/40%) mixture at atmospheric pressure. The breakdown voltage and time to breakdown were registered and the jitter and time to breakdown with respect to DC energisation level and impulse over voltage were analysed. The experimental set up is shown in Figure 1. The switch is pre-stressed with DC voltage through a charging resistor, a HV impulse with a 270 ns duration is generated by a Blumlein pulsed power system.

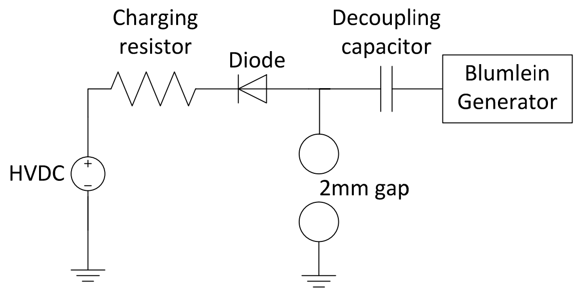

Figure 1. Experimental schematic.

The switch is energised to 6 kV, 7 kV and 8 kV DC level using a Glassman EH series (60 kV) HVDC power supply via a 1 MΩ charging resistor. A Blumlein pulsed power system charged using a sepatrate Glassman EH HVDC power supply (100 kV) and provides an impulse of up to 55 kV with a rise time ~60 ns. The Blumlein is triggering by a trigatron (SAMTECH Ltd) operated by a pulse generator. The rate of voltage rise and the peak voltage depends on the charging voltage of the Blumlein pulsed power generator.

As shown in Figure 1, the triggering impulse circuit is connected to the switch via a decoupling 212 nF capacitor to allow the impulse to pass. The DC circuit is connect to the switch via a 6HV50k HV diode which does not allow negative impulse from the Blumline generator to flow into the DC energisation circuit.

The switch used in this experiment has a compact design with two spherical electrodes placed 2 mm apart. The spheres are 9.5 mm radius made of brass. A Tecktronix TDS 2024 (200MHz, 2GS/s) oscilloscope and Northstar PVM-6 high voltage probe were used to measure the charging voltage to the switch and to the Blumlien. The DC power supplies are left at the fixed voltage for the duration of the test to keep the conditions consistent.

3. RESULTS AND DISCUSSION

This experiment investigated triggered breakdown of a sphere-sphere topology switch filled with 3 different gases: air, nitrogen and a nitrogen/oxygen mixture (60% nitrogen/ 40% oxygen) at atmospheric pressure. To analyse switch performance the time delay to breakdown results had to account for misfire (non-breakdowns). Misfires were assumed to have occurred because the impulse length was not long enough and it was assumed that the duration of the impulse (270 ns) provides a minimum value for pre-breakdown time delay in the case of misfires. 30 breakdown events were measured for each combination of DC and impulsive voltages.

The self-breakdown voltage level of the switch filled with air is 8.32±0.09 kV. Initially, the switch was filled with air, energised to 6 kV, 7 kV and 8 kV and then stressed with an impulse from the Blumlein generator. The Blumlein generator was charged to 19 kV, 25 kV and 35 kV, which resulted in the peak output voltage without breakdown of 25 kV, 35 kV and 55 kV respectively. The rate of rise (*dV/dt*) of the impulses changed from ~0.3 kV/ns at 19 kV charging voltage to ~0.7 kV/ns for 25 kV charging voltage and ~0.9 kV/ns for 35 kV charging voltage. The change in rate of rise had a significant impact on the misfires rate, the time delay to breakdown and the jitter of the switch. Figure 2 shows that the time delay to breakdown significantly reduces as the *dV/dt* (Blumlein charging voltage) is increased.

Impulses generated by the Blumlein generator charged to 19 kV were unable to cause breakdown at 6 kV DC stress level. When the Blumlein energisation level (and *dV/dt*) was increased the time delay to breakdown reduced and the switch operation became more stable. At 35 kV Blumlein charging voltage, the time delay to breakdown converged for each DC charging level providing the most reliable operation and shortest time delay to breakdown, therefore 35 kV charging voltage was used in all further tests.

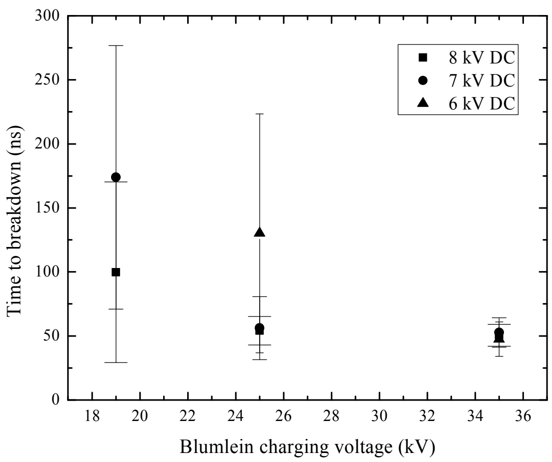

Figure 2. Time delay to breakdown in atmospheric pressure air as a function of Blumlein charging voltage (dV/dt).

Using the Blumlein charging voltage of 35 kV, switch operation in the case of air, nitrogen and a nitrogen/oxygen mixture was investigated: time delay to breakdown, and jitter as a function of DC pre-energisation (6 kV, 7 kV and 8 kV) were obtained.

Figure 3 shows the time delay to breakdown as a function of DC pre-energisation level. Using the same Blumlein charging voltage (*dV/dt*) the time delay to breakdown for all gases reduces when the DC pre-energisation level was increased.

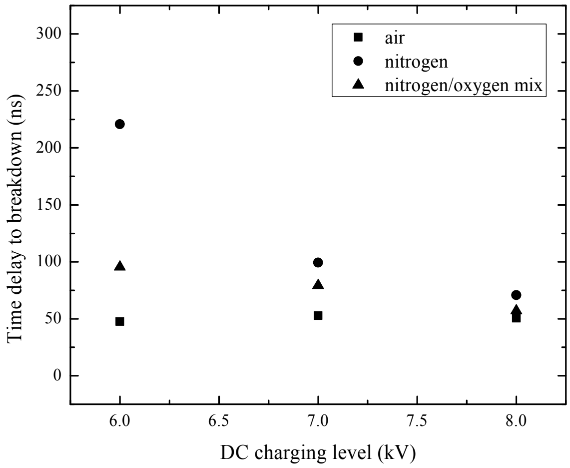

Figure 3. Time delay to breakdown in air, nitrogen and a 60% nitrogen/ 40% oxygen mixture as a function of DC charging voltage using a 35kV charged Blumlein triggering impulse.

It can also be seen that with all charging voltages air has the shortest time delay to breakdown at 8.6 ns when DC energised to 8 kV. Figure 5 displays the standard deviation of the time delay to breakdown data, showing stabilisation as the DC charging level is increased.

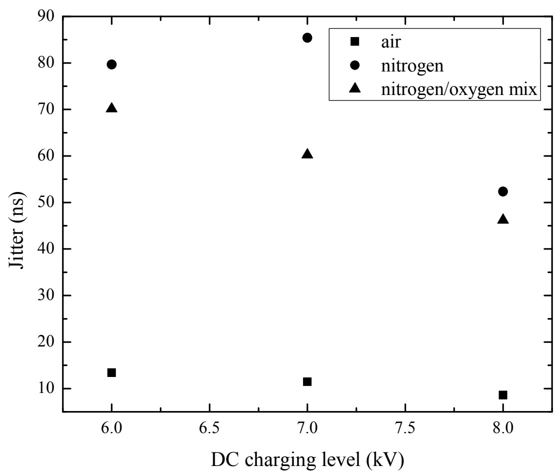

Figure 5. Standard deviation of time delay to breakdown for air, nitrogen and a 60% nitrogen/ 40% oxygen mixture as a function of DC charging voltage using a 35kV charged Blumlein triggering impulse.

Figure 5 shows jitter for all gas mixtures. It was found that the jitter decreases with an increase in DC pre-energisation indicating higher stability of switch operation at higher levels of DC stress. For air the jitter improves marginally however it is 83% lower than for nitrogen for 6 kV DC stress. The jitter for nitrogen and the nitrogen/oxygen mixture reduces significantly with increased DC energisation level, 34% reduction from 6 kV to 8 kV DC stress level.

4. CONCLUSIONS

This paper described experimental performance of a gas filled, two electrode switch, energised and triggered using a DC pre-stress and a short superimposed HV impulse. A sphere-sphere topology was used in the switch which was filled with air, nitrogen and a nitrogen/oxygen mixture (60% nitrogen/ 40% oxygen). Time delay to breakdown and jitter have been obtained for different levels of DC and impulsive stresses and all 3 gases.

It has been found that higher rates of voltage rise, *dV/dt*, for HV impulses provide the shortest time delay to breakdown and lowest jitter in the case of atmospheric air. It was found that charging the Blumlein generator to 35 kV (which produces HV impulses with a rate of rise ~0.9 kV/ns) results in the shortest time delay.

Using this Blumlein charging voltage and 6 kV DC energisation it was shown that atmospheric air results in 83% lower jitter as compared with nitrogen at the same (atmospheric) pressure. As DC energisation is increased to 8 kV the time delay to breakdown reduces to ~50-70 ns for all gases tested, a 68% reduction for nitrogen. The stability (jitter) of the switch, has been shown to be lowest for air and best for all gases at 8 kV DC energisatioin.

It has been shown that using superimposed DC stress and HV impulses a two electrode switch can be used in the triggered regime. Higher rising rates of triggering HV impulses result in reduced time delay to breakdown and jitter. It has also been shown that the use of atmospheric air as a switching medium provides a shorter time delay to breakdown and smaller jitter as compare with nitrogen or the 60% nitrogen/40% oxygen mixture. Jitter as low as 8 ns has been recorded using the superimposed triggering regime.

5. ACKNOWLEDGMENTS

This work has been part-funded by a UK MoD Research Programme.

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