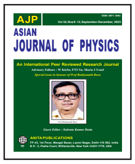

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Development and switching characterization of high power pseudospark switch for fast pulsed power applications

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Dedicated to Prof B N Basu

In this paper, the development and switching characterization of a multi-gap, multi-aperture, pseudospark switch (MGMA-PSS) with and without the saturable inductor (SI) have been presented for fast pulse power applications. Simulation was also performed to understand the discharge growth inside the hollow cavity for the single-gap geometry. The SI not only improved the commutation loss but also proved to be beneficial for sustained operation over a longer life of the switch. The impact of the number of inductor cores was studied and experimental analysis was performed with the different numbers of inductor cores at different anode voltages and background hydrogen gas pressures. The experimental results have clearly indicated the reduction in commutation losses up to ~55%, ~80%, and ~95% with a single toroid core, three toroid cores, and five toroid cores, respectively.

Keywords: Pseudospark discharge, Commutation losses, Hollow cathode, Hollow anode, High-power switch.

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1 Introduction

Gas discharge based high-power switches play major roles in the pulsed power domain for the switching applications. A cold cathode thyratron switch, known as a pseudospark switch (PSS), operates based on the low-pressure gas discharge phenomenon. In fact, the high power handling capability of the pseudospark switch is remarkable for fast pulse power applications. The pseudospark (PS) discharge-based high-power switches are gaining interest worldwide because of their simplicity, robustness, reliability, and reasonable cost as compared to other kinds of switches [1-3]. For instance, a dedicated research group at the Friedrich Alexander University (FAU), Erlangen, Germany, has been involved in the advancement of single-gap PSS for more than 20 years [4,5]. CSIR-CEERI, Pilani has also made several successful efforts for the design and development of PSS, including single gap sealed-off coaxial-PSS (~25 kV, ~5 kA) [6], double gap sealed-off coaxial-PSS (~40 kV, ~8 kA) [7,8], linear aperture radial multi-channel PSS (~20 kV, ~20 kA) [9] and coaxial demountable three-gap PSS (~40 kV, ~7kA) [10,11].

In fact, the prototypes of two- and three-gaps PSS have been developed at very few places worldwide. The pseudospark discharge is not only limited to switching applications but also has many other applications in the field of short-pulsed electron beam generation [12,13]. For the development of PSS of higher hold-off voltages ≥ 50 kV, certain efforts have been made by several research groups worldwide [14]. However, the applications of high-power PSS remained limited due to the commutation losses and anode erosion during

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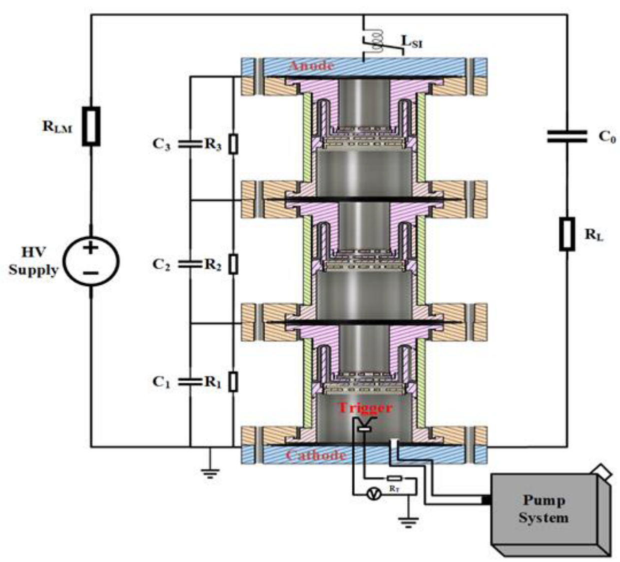
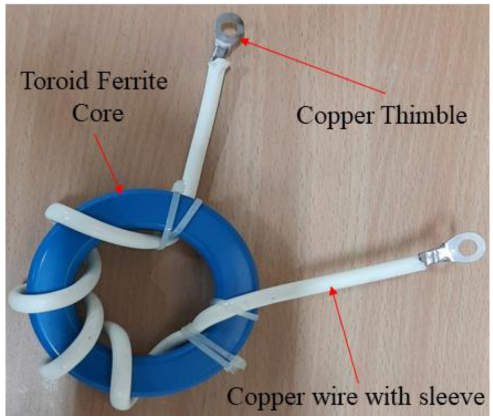
the operation. The pseudospark switches (PSSs) suffer from commutation losses due to the high rate of rise of current during the discharge operation before the voltage drops to zero [14]. For the improvement of the commutation losses, a saturable inductor (SI) has been chosen as the inductor possesses the property to resist the rate of rise of the current [15]. In this paper, the behaviour of the switch has been investigated with and without an SI. A comparative analysis has also been brought out on the performance of the PSS. The experimental setup with the SI is discussed in section 2. The results are presented in section 3, and the paper is concluded in section 4.

2 Experimental Setup

The experimental setup with the external circuit and the designed SI are shown in Fig 1. Three single-gaps are coaxially cascaded to make the three-gaps arrangement with the uniquely designed drift-space region. Chicane is designed for the protection of the gap insulator. The kidney-shaped ring slot electrodes with baffles have been integrated to obtain fast and smooth switching at high voltage with decreased electrode erosion due to high current. For the design of the SI, a ferrite core is selected because of the low hysteresis loss [10,11,16]. An external voltage divider circuit of three equal resistances R_1, R_2 and R_3 of 100 MΩ each and three equal capacitances C_1, C_2 and C_3 of 1 nF each are connected in parallel with each gap. Resistances are used to eliminate the unequal distribution of the voltage across each gap and with the help of capacitors, the plasma is coupled from one gap to the next gap. The anode has been connected to a positive high-voltage supply while the cathode is grounded. The value of the external storage capacitance (C_0) is 360 nF. The capacitors (C_0) are charged by the high voltage power supply (Spellman model SL80P600/220) through the 3 MΩ limiting resistance (R_{LM}). Initially, the rotary pump has been connected to achieve a pressure up to ~10^{-2} mbar and then the turbo molecular pump is connected to achieve the base pressure of ~10^{-6} mbar. Subsequently, with help of the controlling valve, hydrogen gas is filled inside the switch. The pressure gauge is used in the experiment to measure the gas pressure. The high-voltage measurement at the anode is done through the high-voltage probe (North Star, PVM-2). The discharge current has been measured through a current transformer (Pearson 110 model). The voltage and current waveforms have been recorded using a digital phosphor oscilloscope (Tektronix DPO3034). A voltage probe (Tektronix P6015A) was used for the trigger voltage measurement.



(a)



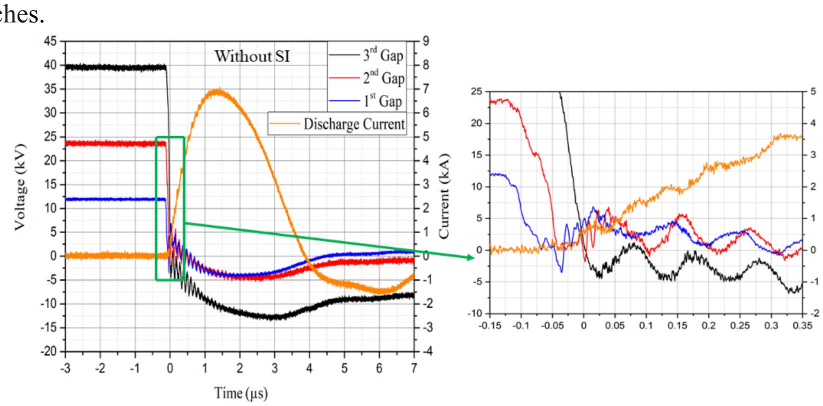
(b)

Fig 1. (a) Experimental setup with the external circuit (b) Designed SI for the experiment.

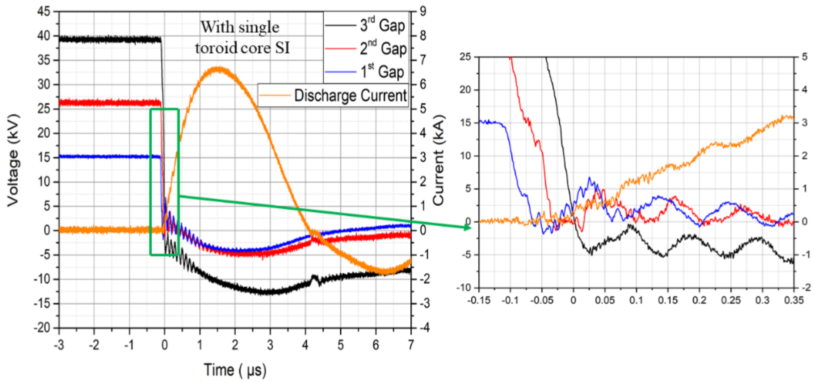
3 Result and Discussion

The experiment is performed for the different applied voltages and the pressure was maintained below 80 Pa. During the experiment, different numbers of toroid inductor cores have been taken for the investigation of the switching characterization of the MGMA-PSS. Different numbers of inductor cores are used to understand the switching behaviour at different conditions. The ferroelectric trigger unit is used to generate the trigger pulse for the switching operation. Switching characteristics without SI and with SI having single-, three-, and five-toroid cores are shown in Fig 2 at 30 Pa gas pressure and applied voltage ~40 kV.

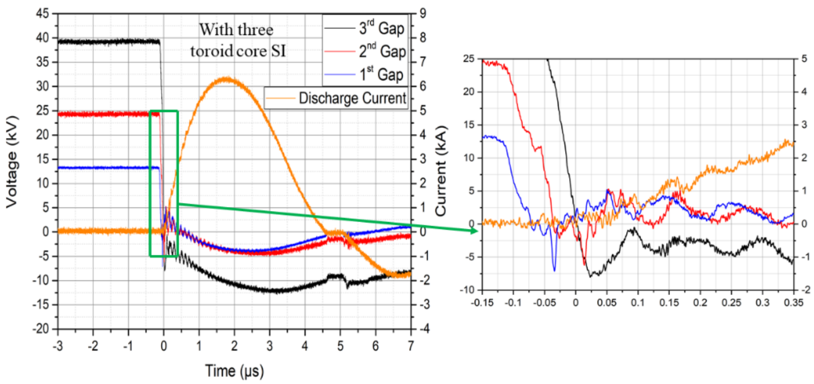
It is observed that the SI leads the delay of ~135 ns with five cores, ~65 ns with three cores, and ~35 ns with the single core in the rise of the discharge current as compared to normal switching operation. This delay is enough to reduce the commutation losses up to ~55%, ~80%, and ~95% with a single toroid core, three toroid cores, and five toroid cores, respectively. Figure 2 shows the zoom scale of all figures is shown between –150 ns to 350 ns. The rising phase of the discharge current becomes smooth when the number of inductor cores are increased. At the applied 40 kV anode voltage, the estimated discharge current from the experimental results with no toroid core, single toroid core, three toroid cores, and five toroid cores are the ~7 kA, ~6.8 kA, ~6.5 kA, and ~6.2 kA, respectively. There is a minor decrease in discharge current with increasing number of inductor cores but the commutation losses are improved up to ~95%. This technique is very useful to overcome commutation losses and also for improving the performance of the high-power gas discharge switches.



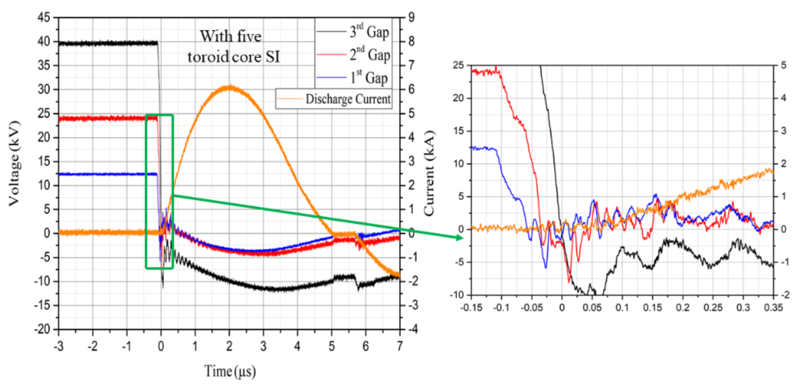
(a)



(b)



(c)



(d)

Fig 2. Switching characteristics with and without SI of MGMA-PSS geometry (a) no toroid core (b) single toroid core (c) three toroid core (d) five toroid core.

In Fig 3, a simulation of the self-discharge mode operation is shown for the single gap geometry at 30 Pa pressure. The simulation is performed to understand the discharge growth and ionization processes inside the hollow cathode during the switching operation. For the simulation of single gap PSS, COMSOL simulation software was used to understand the behaviour of the discharge inside the hollow cavity at different operating conditions [17]. In the simulation, it is observed that the potential penetration inside the hollow cathode is more at higher gas pressure due to the greater number of collisions of the particles [18]. The dense discharge is formed at higher gas pressure as compared to lower gas pressure. It may be concluded that lesser applied potential is required at higher gas pressure and higher potential is required at lower gas pressure for the discharge operation [19].

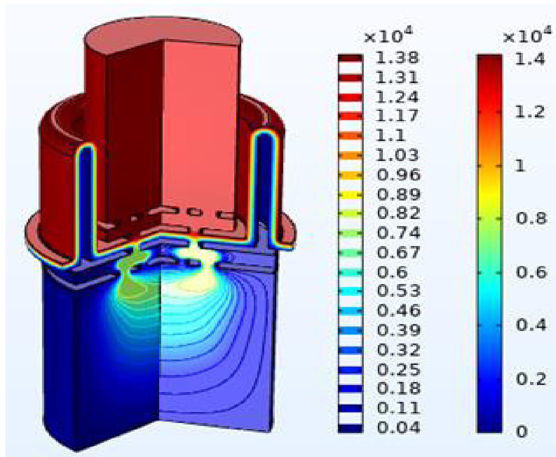


Fig 3. Simulation of the single gap PSS geometry in self-discharge mode.

4 Conclusion

In this study, an experiment was performed with and without the saturable inductor (SI) for the MGMA-PSS and the simulation was also performed for single gap PSS in self-discharge mode to understand the discharge behaviour of the switch. At 40 kV applied anode voltage with 30 Pa background hydrogen gas pressure, the switching characteristics were studied and it was found that there is a significant reduction in commutation losses with more number of toroid cores. The investigation was done with different numbers of inductor cores. The saturable inductor was found useful in improving the performance of the switch and also in improving the commutation losses.

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