

Developments of 500 kV Multi-Channel Multi-Gap Self Breakdown *

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Abstract

A multi-gap multi-channel(MGMC) switch of 500 kV has been developed at Pohang Accelerator Laboratory (PAL). It consists of ten of gaps to increase self-discharge voltage by filling up the gas. A structure of a multi-gap switch can increase its inductances. Thus, in order to solve those problems its structure made by multi-channels had been designed to decrease the inductance effects. The fabricated switch tested using marx generator of 500 kV. The design concept and its characteristics will be discussed.

I. INTRODUCTION

The requirements for developing its switch for high voltage have a peak current of 100 kA, a peak voltage of 500 kV, a pulse width of 1 us, and its rising time of 100 ns. The types of switches handled with such parameters with any reliability are spark gap switch, inverse pinch switch, multi gap multi-channel switch, and rail gap switch. A candidate switch at PAL is a multi gap multi-channel(MGMC) switch that need to decrease the inductance effects by using multi-channels. In the design of the switch, the distance of 6 cm among its gaps make a choice to get the hold-off voltage of about 900 kV to employee SF₆ by approximately four pressures. The multi gap multi-channel switch, which consists of all of nine stacks with the multi-channel and one single gap distances of 6 cm, was designed, fabricated, and has been tested.

II. MULTI-CHANNEL MULTI-GAP SELF BREAKDOWN SWITCH FOR 500 kV

A. Basic Principle of Spark Gap

Figure 1 is approximated by [1]

$$L_{sg} = \frac{\mu_0}{2\pi} \left\{ y_1 \cdot \ln \left[\frac{r_{01}}{r_{i1}} \right] + y_2 \cdot \ln \left[\frac{r_{02}}{r_{i2}} \right] + y_3 \cdot \ln \left[\frac{r_{03}}{r_{i3}} \right] \right\} \quad (1)$$

Herein, r_{i2} is the radius of the conducting channel, $r_{i2} \ll r_{i1}$ and r_{i3} , and the outside radius of all sections are equal, $r_{01} = r_{02} = r_{03}$, the inductance of the entire spark gap is, therefore, approximately

$$L_{sg} \approx L_a = \frac{\mu_0}{2\pi} \cdot y_2 \cdot \ln \left[\frac{r_{02}}{r_{i2}} \right] \quad (2)$$

where L_a is the arc channel inductance. The small arc channel diameter results in a relatively large inductance, nearly independent of the external conductor geometries. For this reason, multiple, parallel arc channel spark gaps are commonly used to increase the effective radius of current flow and thus reduce the switch inductance.

$$t_L = 3 \cdot \tau_L = 3L_a / (Z_0 + R_L) \quad (3)$$

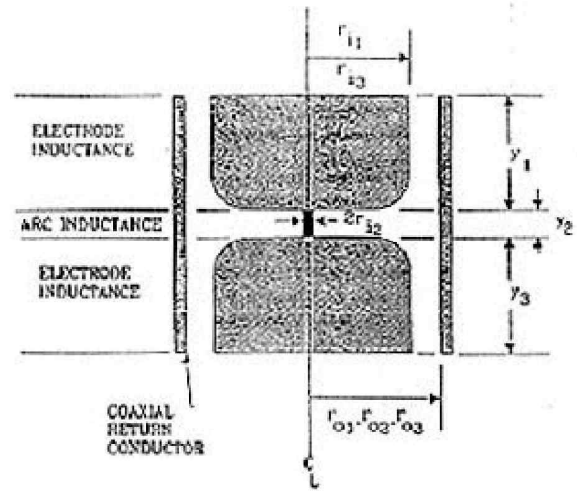


Figure 1. Spark Gap Inductance Geometry

The diameter of the conducting channel, or the number of current sharing channels are the dominant factor in determining the inductance of a spark gap.

Thus, the requirement of its design is to decrease the inductance for holding rise times of the current through electrodes of a spark gap. Its gap distance especially should be narrowed to reduce inductances to emanate

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from arc. In general the high voltage hold-off may be attained by the use of the high- or low-pressure side of the paschen curve (see Fig. 2), by adjusting the gap distance of electrodes, by adopting the multigap electrode, by using high-pressure electronegative gases, or by combinations of these options. The gap distance between the inner and outer electrodes may be adjusted according to the pd value on the paschen curve for the given gas breakdown voltage. The selection of the type of gas and the pressure may be made in addition to adjusting the gap.

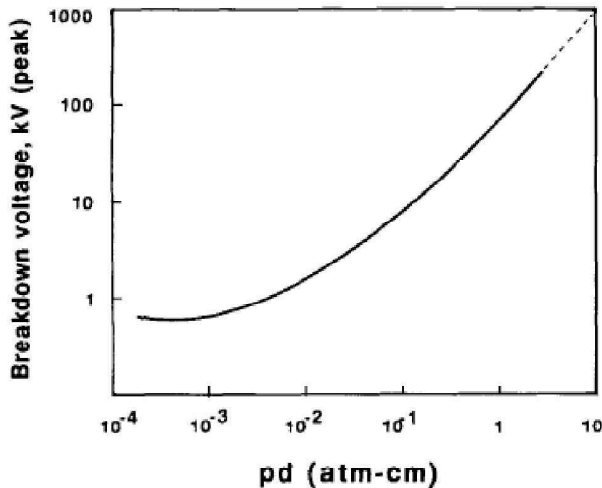


Figure 2. paschen curve for nitrogen. [3]

The gap breakdown voltage endured between the gaps which is separated from air is illustrated through the equation,

$$V_b = 6.72(pd)^{1/2} + 24.36(pd) \quad (4)$$

The hold-off voltage was found to be strongly dependent on both the impulse voltage rise time and the gas mixture composition. SF_6 , which is capable of insulation effect more than double intensities which are compared with air, can be employed generally as a high voltage insulator. Figure 3. shows the gas mixture, 60% N_2 , 40% SF_6 , employed tells us about improving insulation intensity of the nitrogen.

Table 1. Gas parameters against air.

Gas	Relative strength
N_2	1
CO_2	0.9
SF_6	2.3-2.5
Freon	2.4-2.6
CCl_4	6.3

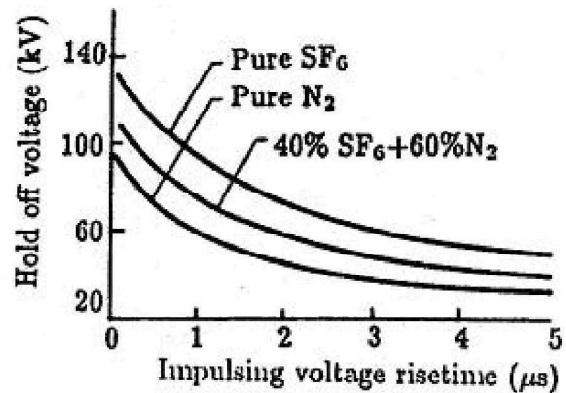


Figure 3. Hold-off voltage as a function of gas composition and voltage rise time .[2]

B. Design the Spark Gap Switch

All spark gaps will break down or transition from the insulating state to the conducting state, if the voltage across the gap is increased above the gap self breakdown voltage. The self breakdown voltage for a uniform field and a given gap spacing, gas specie and pressure, electrode materials, and dielectric environment is commonly described by the paschen curve as discussed above. The requirements for developing its switch for high voltage have a peak current of 100 kA, a peak voltage of 500 kV, a pulse width of 1 μs , and its rising time of 100 ns.

The gap distances affect to decide its hold-off voltage as well as inductances. To get its hold-off voltage of a required 500 kV by using the SF_6 gas, it need the gap distances over 4 cm at a 3.5 pressure from SF_6 , as shown in Figure 4. Thus, At high pressures, paschen's law fails, and an increase in pressure at a constant gap distance results in saturation in the breakdown voltage, as shown in Figure 4.

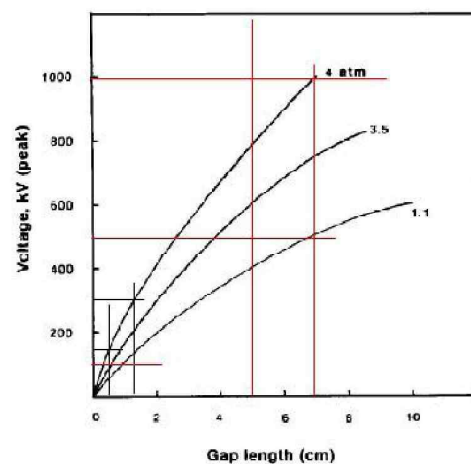


Figure 4. Breakdown voltage vs. gap length for different SF_6 pressures. [3]

There are a rail-gap switch and a multi-gap multi-channel (MGMC) spark gap switch that have a low inductance and also endure HV hold-off voltage. Thus, if spark gap switch for a concept of MGMC would be developed, it is possible to design a low inductance switch, as shown in an aquisition (5). The inductive rise time is:

$$\tau_L = (L_a / N + L_h) / Z \quad (5)$$

with L_a : inductance of a single arc
 L_h : inductance of switch hardware.

For the low impedance systems considered here and single channel operation the inductive rise time dominates the total rise time. With increasing number of channels the resistive rise time becomes more important and the influence of the switch hardware inductance L_h increases.

The breakdown over the surfaces of these spacings has to be considered. It is known that the surface breakdown voltage does not increase proportionately with SF_6 gas pressure. Figure 5 shows the insulating spacer efficiency, the ratio of the breakdown voltage over the spacer to that of the gas gap with the same distance, versus SF_6 pressure. To obtain the hold-off voltage desired, the spacer must have a distance twice that of the gas gap.

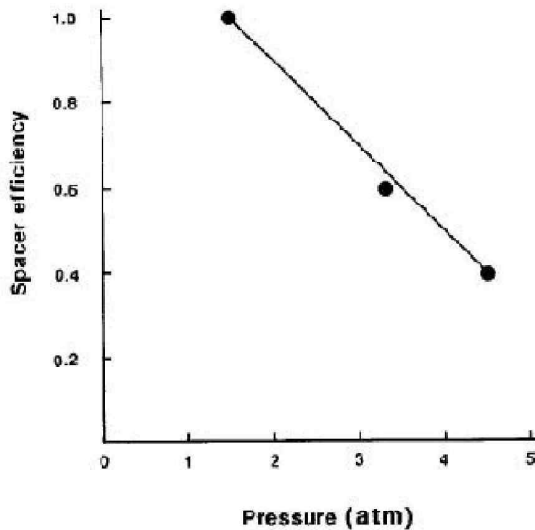


Figure 5. Spacer efficiency vs. SF_6 pressure. [3]

C. Fabrication and Test of the MGMC Switch

1) Fabrication of the MGMC Switch

The MGMC switch has been designed, and the structure and the picture of the switch are shown in Figure 6 and 7. The basic structure of the fabricated MGMC

switch is similar with a Russian's MGMC which consists of a structure to trigger multi-channel discharges by displaying beads equally on the circular shape. In case of the Russian's MGMC it has a low breakdown voltage because the beads lay on the wall. As shown in Figure 6, the shape of the fabricated MGMC switch is that the beads put in between insulator sheets. The structure of the designed MGMC switch consists of 8 discharge channels to employ 8 beads.

The gap distances were chose to 6 cm to get a hold-off voltage of approximately 900 kV by using a SF_6 at a 4 pressure. All of the multi-channel gap and single gap distances were arranged equally with 6 cm.

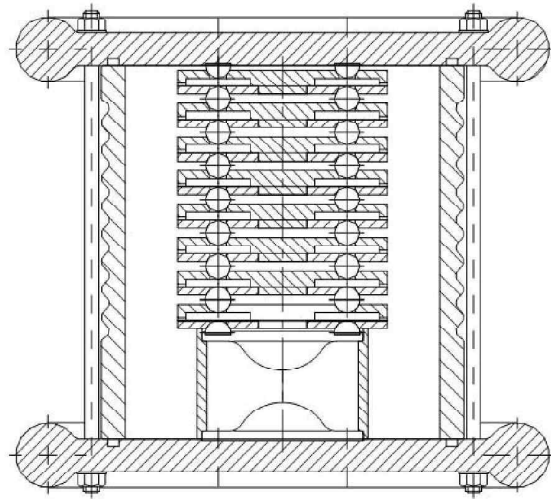


Figure 6. The draft of MGMC switch



Figure 7. The picture of MGMC switch

2) Test result of MGMC Switch

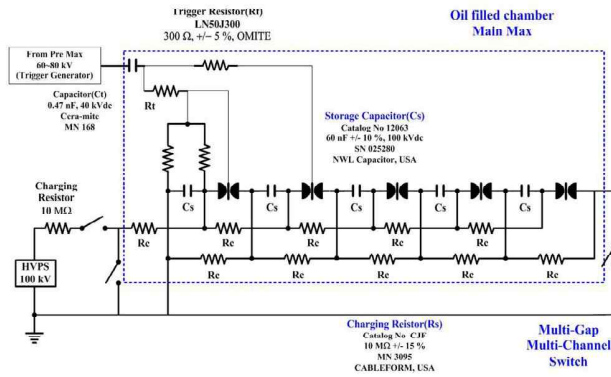


Figure 8. Marx circuit for testing MGMC switch

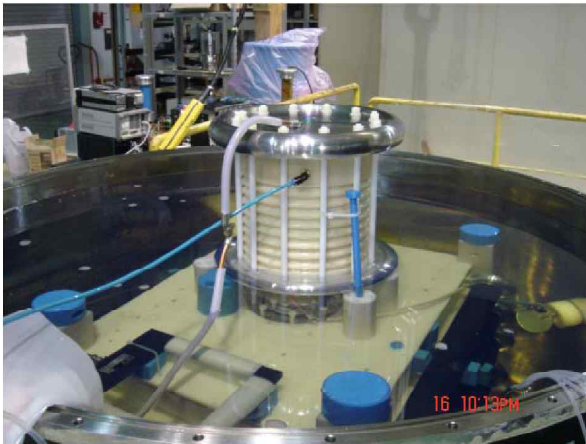


Figure 9 The picture of MGMC switch on Marx

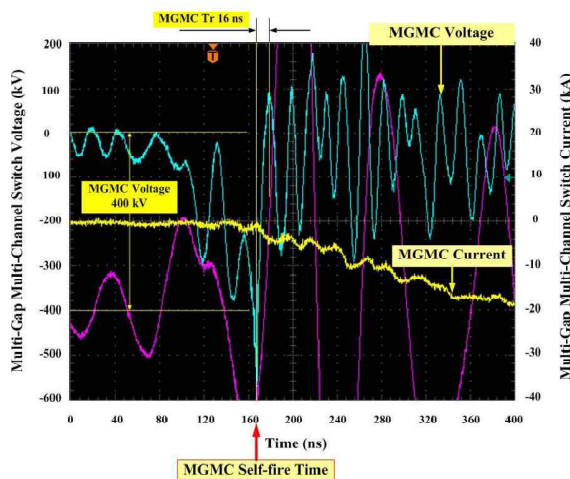


Figure 10. Waveforms measured voltage and rise time of MGMC switch

Figure 8 shows Marx circuit for testing MGMC switch. Figure 9 shows the picture of MGMC switch on Marx in a tank that need oil immersed insulation. The nitron gas, according to the using voltage, can be provided through a

hose that attained on a side of MGMC switch to operate very well MGMC switch. Figure 10 is waveforms that is measured with voltage and rise time of MGMC switch. The switch worked at approximately 400 kV very well, and its rise time is 16 ns.

Figure 11 is voltage and current waveforms of the MGMC switch. The measured voltage and current are 400 kV and 26.5 kA respectively as shown in Figure 11. In order to get an optimum operating condition from a picking gap of MGMC switch, the result from continuous experiment is that 0 psi at 200 kV, 5 psi at 250 kV, 10 psi at 300 kV, 15 psi at 350 kV, and 20 psi at 400 kV.

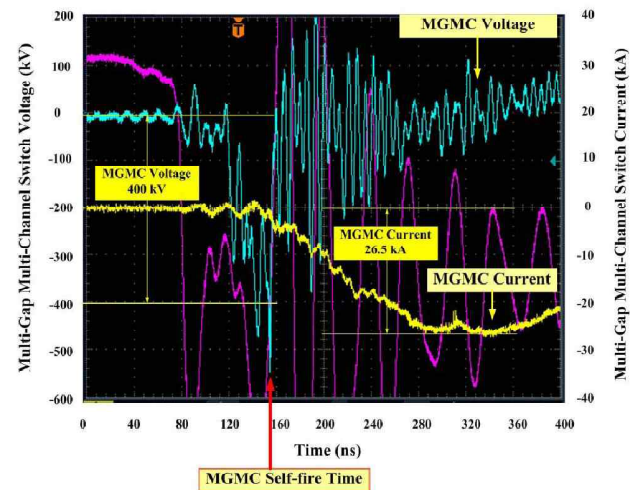


Figure 11. A voltage and current waveforms of MGMC switch

III. CONCLUSION

A high voltage shorting switch for 500 kV has been designed, fabricated, and tested up to full power of 400 kV. The structure of designed MGMC switch consists of 8 multi-channel switches in the form of a bead to reduce switch inductance, and it make up 8 multi-gaps and one single gap. The fabricated switch was tested by using marx generator of 400 kV. The measured rise time is approximately 16 ns. The condition of self-discharge is discovered.

II. REFERENCES

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