Chapter 5

Pulsed Power Switches

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Pulsed power systems generating very high voltages ranging from 100's of kV to a few MV and current in the range of kA to MA requires switches capable of switching energy from high voltage generator to pulse compression stage and finally to a desired load. Most desirable ratings of switches to be used in pulsed power system are infinite voltage and current, with minimum switching time, less delay time, ease of control over switching, long life etc., The major types of switches used in pulsed power system listed are electro-mechanical, vacuum switches, gas switches and semiconductor switches. This chapter presents a brief note on spark gap closing switches in detail along with Thyratrons, ignitrons, solid state switches. Generally, closing switches namely Thyratrons, pseudo sparkgaps operate in glow discharge mode and spark gaps, ignitrons operate in arc mode.

5.1. Spark gaps

Spark gap closing switches are made of two metal electrodes separated by a gap filled with insulating medium. The breakdown strength of any gas depends on its pressure and electric field applied. The relation between breakdown strength of any gas and product of electrode gap to gas pressure is known as the Paschen curve. Paschen curve is different for different gases. Figure 5.1 shows a typical Paschen curve [1] and various stages of switching gas switches. Gas switches makes use of insulation properties of different gases under high pressure working on right hand side of Paschen curve.

Spark gaps are a versatile type of gas switches which can be fabricated to suit a particular requirement. They offer wide range of operating parameters like voltage, current, coulomb transfer, repetition rate, low losses, self-healing etc., Performance of gas filled spark gaps are affected mainly by electrode erosion, and size is dictated by surface breakdown strength either sides of housing. Figure 5.2 shows a typical 100 kV spark gap used in KALI-30 GW system.

The spark gap electrodes can be made in different shapes namely parallel plates, sphere- sphere, cylinder-cylinder, and rod-plane etc. Parallel plate configuration is mostly preferred for reliable break down of the spark gap as the electric field in the gap is uniform. Practically, the electrodes are designed to have flat region at the centre and curved outwards at their edges. This ensures the enhanced electric field in the gap region, to make sure that breakdown takes place in the gap region only.

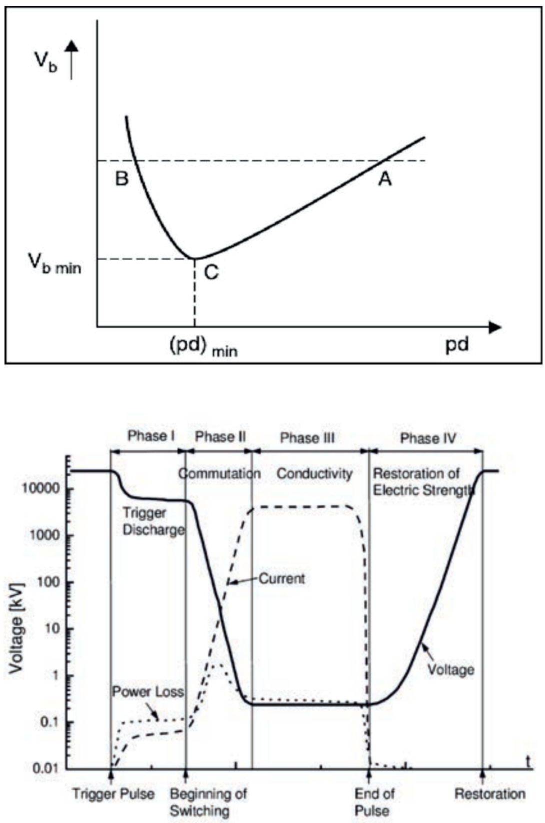


Figure 5.1. Typical Paschen curve and various temporal stages of switching [1].

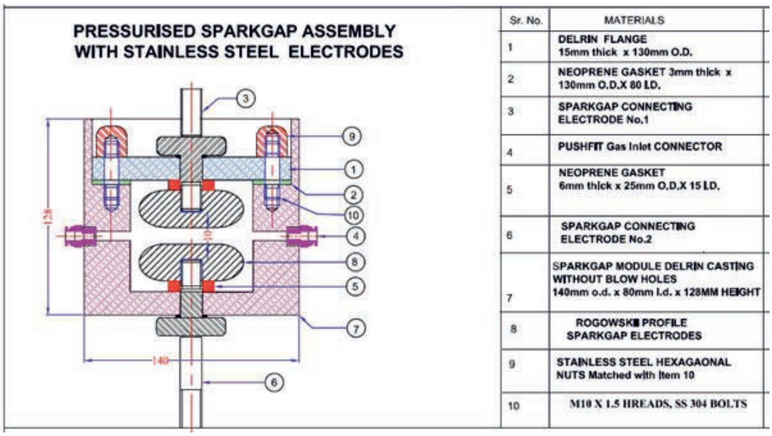


Figure 5.2. 100 kV Spark gap used in KALI-30 GW pulse power system.

5.1.1. Cascaded Spark Gaps

Spark gaps can be made with more than two electrodes, to withstand voltages ranging from 100s of kV to few MVs. Such spark gaps are called cascade spark gaps, in which single large gap is replaced by a series of smaller gaps. Such spark gaps may provide faster switching time in relation to larger one. Figure 5.3 shows the drawing of 600 kV cascade spark gap with diameter of 300 mm and 300 mm long.

In cascade spark gaps [2], as the number of gaps are in series, the withstanding voltage divided among each gap, thereby reducing the gap length. The voltage division among the gaps may be very well equally distributed by using suitable grading resistors.

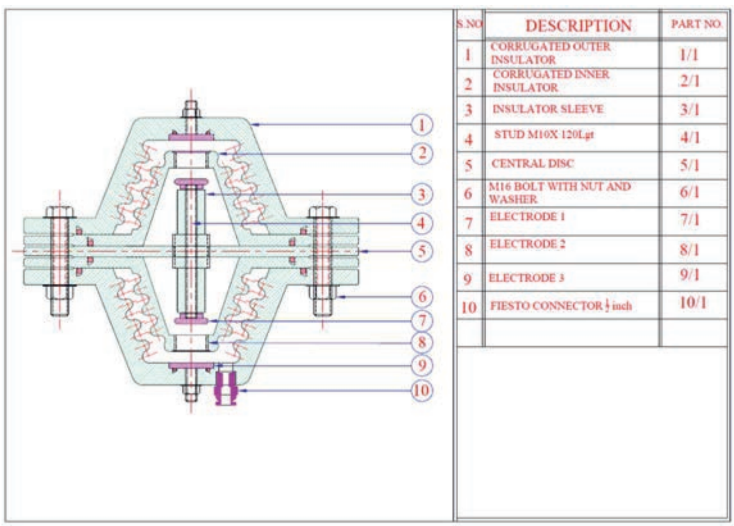


Figure 5.3. 600 kV Cascade gap.

A 500 kV, 3 mm hemispherical single gap spark gap is developed to study the pulse breakdown voltage with high purity nitrogen at different pressures is shown in Figure 5.4.

Liquids like water, glycerine, transformer oil can also be used as insulating medium in spark gaps. Like gas spark gaps, liquid spark gaps are self-healing, withstand high hold off voltage which means less gap distance leading to less inductance. Liquid spark gaps are usually used in liquid insulated coaxial pulse forming line, Blumlein pulse forming line. Liquid spark gaps can be used in repetitive mode limited up to 10 Hz as the impurities in liquid does not get enough time to settle down to regain its dielectric strength.

5.2. Thyratron

Thyratrons [3] are low pressure hydrogen filled unidirectional switch, whose closure is obtaining by grid control. Thyratrons are capable of hold off voltages up to 100 kV and can carry current up to 40 kA with a jitter of 1-5 ns and can be repetitively pulsed up to 1 kHz. Hydrogen filled Thyratrons exhibits smaller switching time and carry peak current due to low mass and high mobility of atoms. They are commonly used in trigger generator circuits for spark gaps and ignitron.

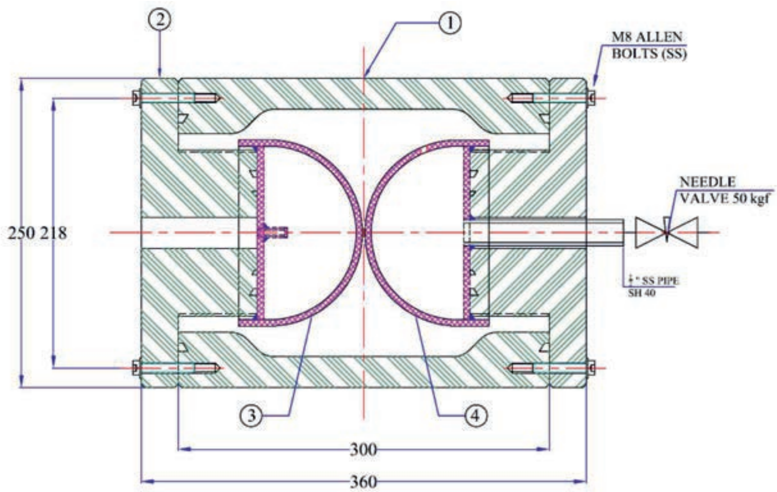
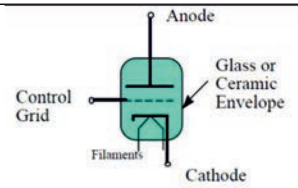
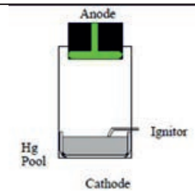


Figure 5.4. 500 kV, 3 mm spark gap.

5.3. Ignitron

Ignitron [3], unidirectional switch, makes use of mercury pool as cathode for switching. Ignitrons are capable of hold off voltages up to 50 kV and can carry current up to 100's of kA with a jitter of 10-50 ns and can be repetitively operated with 1 Hz.

Table 5.1. Comparison of thyratron and ignitron parameters.

Description	Thyratron	Ignitron
Symbol		
Medium	H_2, D_2	Hg
Control	Grid	Ignitor and grid
Max voltage	100 kV	50 kV
Max current	50 kA	200 kA

5.4. Semiconductor Switches

Recently, solid state switches are widely used in high voltage modulators, power supplies, and trigger generator etc., Moreover high voltage withstanding capability and high current rating solid state switches are being developed to replace Thyratrons, ignitrons, etc. Comparison of commercially available power semiconductor devices [4] ratings are tabulated in Table 5.2.

Development of solid state switches using silicon carbide, have voltage rating up to 20 kV, 8 kA but not commercially available.

Table 5.2. Comparison of Solid state switches parameters

Device Type	Max Freq	Max V/A rating	Gate control
Diode	Slow - fast	6 kV/10 kA	Circuit commutation
Thyristor	Slow, 1 kHz	12 kV/5 kA	Current pulse triggered on
GTO	Slow, 1 kHz	6 kV/6 kA	Current pulse triggered on and off
MCT	Med, 30 kHz	3 kV/2 kA	Voltage pulse triggered on and off
MOSFET	Fast, 1 MHz	1.5 kV/500 A	Voltage level controlled on and off
IGBT	Med, 80 kHz	6.5 kV/3.6 kA	Voltage level controlled on and off
BJT	Med, 10 kHz	1.7 kV/200 A	Current level controlled on and off

References

[1] Hansjoachim Blumh, Pulsed power systems Principles and Applications, Springer, 2006.

[2] John Lehr and Prahlad Ron, Foundations of Pulsed Power technology - IEEE Press, Wiley, 2017.

[3] C. Burkhart, Pulsed power engineering switching devices, SLAC National Accelerator Laboratory, 2009.

[4] ABB Power semiconductors product catalog 2020.