A STUDYOF HIGH-POWER SWITHC WITH THYRISTOR FOR PULSE POWER APPLICATIONS

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Abstract

High power pulse switches, such as thyratrons, ignitrons, sparkgaps etc, have been used for pulsed power generators. Recently, various semiconductor switches, which can handle high voltage and high current, are researched and developed for pulse power applications, and they are expected to replace conventional discharge switches due to the fact that the semiconductors have advantages of long lifetime, high reliability and small size. We have designed and built a fast thyristor assembly that consists of 8 thyristors (ABB; 5SPR-26L4508-8-WC) in series to generate high power pulses; 7μs pulse width, 12.6 kA anode peak current at 20 kV, and 300 pps (pulses per second). Fast turn-on measurement to a 4 μF capacitive load in low inductance circuit has been successfully performed to have 10 kA/μs at the peak current of 12.6 kA with the anode voltage of 20 kV. This paper presents the design of the thyristor switch assembly and its test results.

1 INTRODUCTION

There are two types of generating high power pulses. One is making discharges on the primary of pulse transformer and the other is directly on high voltage side. Main parameters are inductance and capacitance of circuits in both types. The switch in the system that demands rapid rise time and narrow pulse width requires characteristics of low voltage drop at turn-on and sufficient liability at sudden high current. This paper is intended as an investigation of semiconductor resistance at turn-on and the transmission characteristics at high surge current.

2 SYSTEM DESCRIPTION

2.1 Assembly

A semiconductor switch assembly for high power switching employed ABB semiconductor (5SPR-26L4508-8-WC) device. The switch connected by 8 silicon semiconductors (91mm dia.) in series was combined with heat sink and fixed by insulation press frame.

Figure 1 shows the appearance of the switch assembly. Each component has a gate drive and drive power circuit. Isolated power transfer is realized by using ferrite transformer in the PCB. The single pass primary winding is powered by external SMPS (switch mode power supply) with switching frequency of 25 kHz, and primary current of 4 A_{P-P}.

Fig 1. 5SPR-26L4508-8-WC Reverse Conducting Discharge Switch Assembly

The performance of the solid-state switch was studied with a capacitor bank. Fig.2 shows the circuit diagram of the switch test circuit. Test load is 4 μF capacitor. R1, R2 and D1 protect a power supply from reverse current at abnormal state. A series inductor with the switch is equivalent inductance of a coaxial cable between the capacitor and the switch. The inductance is measured 2.5 μH by LCR meter.

Table. 1 Specification of the semiconductor switch

Parameter	Value
Blocking voltage (kV)	30
Clamping force (kN)	40(+10% -15%)
Clamping method	Belleville spring pressure pack
Cooling	Deionize water
Device in series (PCS)	8
Di/dt (kA/μs)	≤ 10
Jitter for trigger (ns)	< 50
Max. charge voltage (kV)	20
Peak current (kA)	12.6
Pulse width (μs)	12
Rep. Rate (Hz)	300
Silicon size (mm)	Ø 91
Switch on time (μs)	300
Triggering	Optical

The inverter power supply (Maxwell, 30 kV, 0.5 A, 8 kJ/S) charges the capacitor up to 20 kV with a charging time of 16 ms. After capacitor C1 is charged up to an applied voltage Vo, a fast thyristor turns on by gate switching and an output current I_{out} is obtained at the output switch. The anode voltage of the switch was measured by a North Star high voltage probe (PVM-5) and the anode current of the switch was measured by a Pearson's current transformer (model 3025) at the return line of the switch.

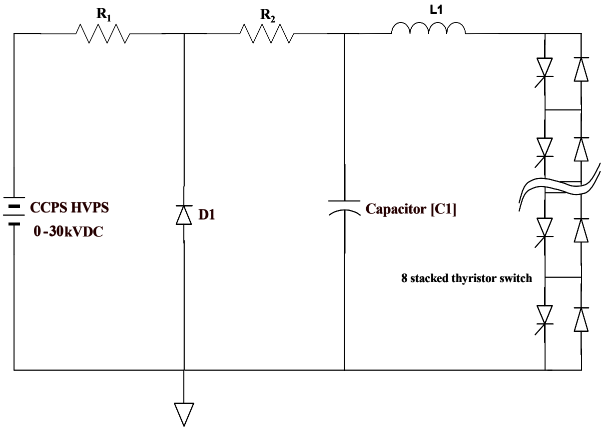

Fig. 2 High voltage experimental circuit

2.2 *Circuit analysis*

Fig. 3 is the equivalent circuit of high voltage semiconductor switch. An equation can be written by using Kirchhoff's voltage law:
The value of the current i is given by the term:

$$\begin{aligned} E &= V_R + V_L + V_C \\ &= iR + L\frac{di}{dt} + \frac{1}{C}\int i\,dt \qquad [V] \end{aligned}$$

$$i = \frac{2Ei}{\sqrt{\frac{4L}{C} - R^2}}\, e^{-\frac{Rt}{2L}} \sin\frac{\sqrt{\frac{4L}{C} - R^2}}{2L}t \qquad [A]$$

The voltage equations are as follows. The maximum value of the current (Io) is given by the term :

$$Io = \frac{2Ei}{\sqrt{\frac{4L}{C} - R^2}} \qquad [A]$$

The ringing behaviour of the current in an underdamped circuit is shown in Fig. 4.

2.3 *High voltage test*

High voltage test was performed on the three stages. First stage is to recognize the voltage and current sharing between the semiconductors and operation state of other components at 2 kV. In the Second stage, the performance of the switch was verified with applying gate signal at 8kV and then voltage was gradually increased up to switch's regulated voltage.

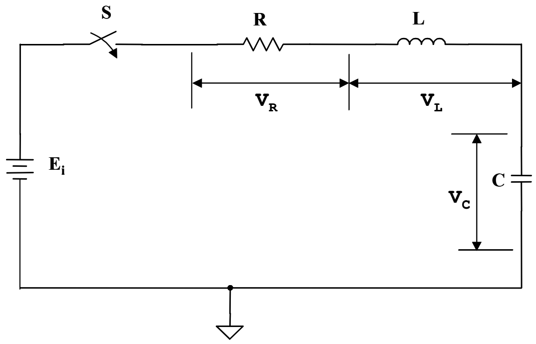

Fig. 3 High voltage test equivalent circuit

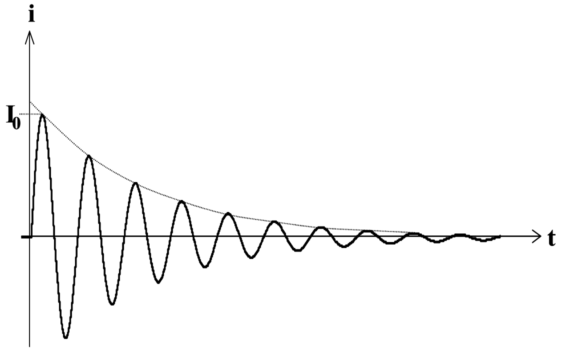

Fig. 4 Underdamped current wave

Equivalent circuit of the switch assembly for computer simulation is shown in Figure 5. Measured voltage current and the computer simulation result were compared in Figure 6.

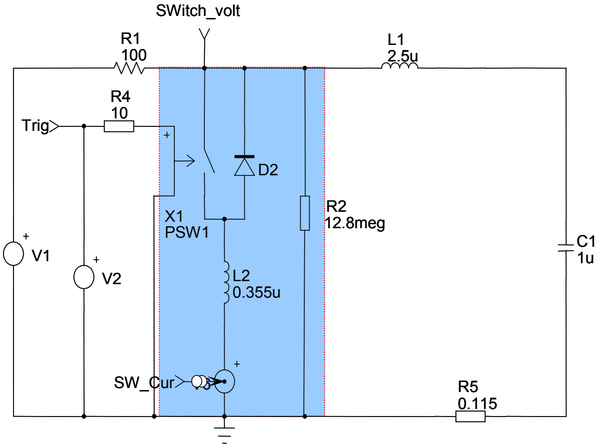

Fig. 5 Computer simulation equivalent circuit

Efficiency of the switch assembly maintains over 90%. Around 10% is loss. 5% of total 10% loss is switch loss, and the loss is corresponding to 6.

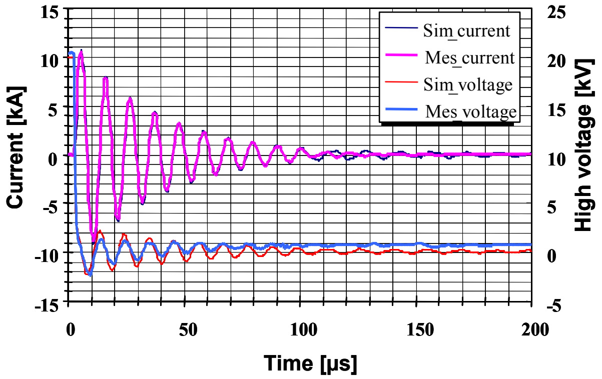

Fig. 6 Simulation and measurement of waveforms.

kW, therefore efficient cooling due to switch loss was needed. Water cooled heat sinks (ABB, 5SAB20V0800, 116 mm dia.) was adopted

De-ionised water was employed for electrical insulation and its flow rate and pressure was designed as 3 liter/min and 1.5 bar respectively. Output temperature of cooling water was 29 °C with 25 °C at inlet for 6 kW energy loss, which was 5.5 K/kW of maximum cooling capability.

Figure 7 shows switch voltage and current waveforms during the high voltage discharge. Table 2 indicates calculated switch parameters for two different test circuits.

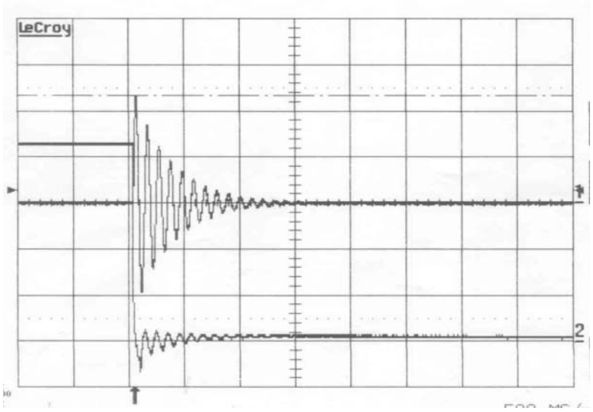

Fig. 7 switch voltage and current waveforms

3 RESULTS

We obtained the waveforms with 11.6 kA of peak current, 11.38 μs of pulse width from high voltage discharge system at 20 kV of regulated voltage using the semiconductor switch assembly. Circuit total resistance and switch resistance were calculated by turning on the switch with energy storage capacitor in parallel. Power loss at regulated voltage was calculated at the operation condition.

Load test was performed under 150 kV peak voltage, 9 kA peak current, 7 μs pulse width and 270 pps. Internal impedance should be minimized in high power pulse system to reduce the power loss. We plan to study further for detailed analysis of the discharge circuit under the operating conditions of high repetition rate and actual load test.

Table. 2 Switch test parameter

Parameter			**Unit**	**PLS**	
Input voltage			kV	21	12
Current(calculated)			kA	13.8	16.3
Capacitor(calculated)			μF	1	4
Inductor(calculated)			μH	2.3	2.3
Resonant impedance			Ω	1.52	0.758
Pulse width(calculater)			μs	9.63	19.06
Measurement value					
Current(measured)			kA	11.6	12.4
Capacitor(measured)			μF	1	4
Inductor(calculated)			μH	3.28	3.75
Resonant impedance			Ω	1.81	0.967
Pulse width(measured)			μs	11.3	24.33
Switch inductor			μH	0.98	1.45
Switch on resistor			mΩ	86.1	59.6
Damping resistor			mΩ	288	154
Measurement of ESR for capacitor & inductor					
Unit[mΩ]	L-ESR	C1-ESR	C2-ESR	SW-ESR	Total-ESR
C1[μF]	-	78	-	-	-
C2[μF]	-	-	35	-	-
L+C1	35	115	-	85	200
L+C2	25	-	59	37	96

6 REFERENCES

[1] E. Ramezani, E. Spahn, G. Bruderer, “High Voltage Thyristor Switch for Pulse Power Applications”, *10th IEEE International Pulsed Power Conference,* 1994.

[2] A. Welleman, U. Schlapbach, E. Ramezani. “Plug and play solid state switching sustem for laser applications”, *12th IEEE International Pulsed Power Conference,* 1999.

[3] A. Welleman, E. Ramezani, J. Waldmeyer, S. Gekenidis, "Semiconductor components up to 12 kV and 150 kA for closing switches" *12th IEEE International Pulsed Power Conference,* 1999.

[4] E. Ramezani, E. Spahn, G. Bruderer, "A novel high current rate SCR for pulse power applications" *11th IEEE International Pulsed Power Conference,* 1997.

[5] Santokh S. Basi, “Semiconductor Pulse and Switching Circuits” pp. 107-126, 1980.