A Development of 1 kHz, 50A, 100 kV IGBT Switch with 420A Breaking Current Capacity

Masaki Tsuneoka*, Member, Tsuyoshi Imai**, Non-member
 Nobuyoshi Nakayama***, Non-member, Toshimitsu Iiyama***, Non-member

This IGBT switch consists of 100 IGBT elements connected in series and each rating is 1700 V, 400 A. This paper reports the test results of 1kHz, 50 A, 100 kV switching and 420 A short circuit breaking. The successful results of it indicates the promising view as the modulator for a gyrotron or a klystron that the output is higher than 1 MW.

Keywords: 1 kHz, 50 A IGBT switch, 100 IGBT elements connected in series, 420 A breaking

1. Introduction

Gyrotron, klystron and vacuum tubes for fusion plasma experiment and accelerator requires DC UHV power supply which output is about 100 kV and tens ampere. To protect the tube, the power supply is needed to break internal arching current and over current with 10 Joule allowance of energy. Authors have developed the switch using 100 IGBT elements connected in series.^[1] Recently, more than 1 kHz of switching frequency is required to the switch to modulate the gyrotron output power.^[2] This paper reports the test results of switching performance of 1kHz, 50A and 100 kV, and current breaking at short circuit.

2. Description of the IGBT switch

Figure 1 shows a schematic diagram of the IGBT switch and the test circuit. The nominal parameters of the switch are shown in Table 1. The switch adopts a Main Switch (MS) of 100 IGBT elements connected in series and a Current Limiting Reactor (CLR) of 1mH with free-wheel diode and resistor. As 2 IGBT elements of 1700V, 400A each are paired, 50 pairs are used in MS. And each of it has a snubber circuit of 0.25 μ F capacitor and resistor. The trigger control unit is able to provide the turn on/off signals to all the gate circuits simultaneously through 100 separate optical cables. The Over Current (OC) detector and shunt resistor send the Turn-Off Command (TOC) to the trigger control unit in case of over current of 200 A. At continuous switching operation, the dominant switching-losses are estimated 33.5 kW at the snubber resistors and IGBT elements in MS and 1.8 kW in the free-wheel diode and resistor of CLR at the 50 A, 1 kHz switching operation at 100 kV.

3. Demonstration of current breaking and switching

Current breaking tests are carried out using a copper wire as the load of which diameter and length are 0.1 mm and 1 m each. Figure 2 shows the characteristics of current(I), and the terminal

Table 1. Nominal parameters of the IGBT switch.

Rating	DC 100 kV, 100 A
Breaking current	420 A, 100 kV
IGBT element	1700 V, 400 A (MG400V2Y60A)
Connection	100 in series - 1 parallel
Switching frequency	1 kHz at 100 kV, 50 A
Switching-losses	33.5 kW in MS and 1.8 kW in CLR

voltage of MS (V_{ce}) in the test. The OC detector outputs TOC to the trigger control unit with 0.6 μ s delay after the detection. The current rises up to 420 A of the peak after 1.8 μ s from TOC. The current breaking starts right after the peak and the turn-off time is 4 μ s. The $I^2 t$ value^[1] derived from Fig.2 is 0.4 Joule/ Ω . As maximum resistance of the copper wire is 12 Ω at 1027 $^{\circ}$ C, the leakage energy is estimated less than 4.8 Joule. This value satisfies 10 Joule energy allowance and there happens no failure on the IGBT switches and the copper wires during the breaking test. At the 420 A current breaking, the snubber circuit suppresses the over voltage which is caused by the electromotive force of a loop inductance in the test circuit. The over voltage is 10 kV at the terminal voltage of 110 kV.

A continuous switching operation of the 500 kJ with the dummy load of 2 k Ω is tested. Figure 3 is the operation results with the conditions that the duty cycle is 1%, flat-top is 10 μ s, the switching frequency is 1 kHz at 100 kV and duration of the operation is 10s. Every after the moment of turning-on, the peak current goes up to 85 A which is over the flat-top of 50 A due to the stray capacitance in the dummy load. The switching losses are cooled down by forced water cooling of 20 liter/minute. The temperature in the heat sinks rises by the snubber circuit and that of the element goes up also about 5 $^{\circ}$ C after the operation.

The IGBT junction temperature is at 61 $^{\circ}$ C with the DC current condition of 100 A and the inlet coolant temperature is 30 $^{\circ}$ C.

4. Summary

An IGBT switch capable of 420 A current breaking at short circuit, and 1 kHz switching under 50 A flat-top current and DC 100 kV operation has been developed now. And the current breaking and switching operation tests are already to demonstrate.

(Received July 10, 2002 and accepted September 10, 2002)

* Nagaoka National College of Technology,
888 Nishikataai, Nagaoka, Niigata, Japan 940-8532

** Japan Atomic Energy Research Institute,
801-1 Mukaiyama, Naka, Ibaraki, Japan 311-0193

*** IDX Corporation
568-113 Ishizuka, Sano, Tochigi, Japan 327-0103

Fig. 1. Schematic diagram of the IGBT switch.

Fig. 2. The characteristics of the current(I) and terminal voltage of Main Switch (Vce) at short circuit breaking test.

Fig. 3. The time behavior of the terminal voltage and the current of dummy load of 2 kΩ, in the 100 kV, 1 kHz switching.

References

- (1) M.Tsuneoka, et al., "Development of High efficiency and crowbar switch-less dc power supply for 1 MW CW CPD gyrotron" *I.J.ELECTRONICS*, Vol.86, No.2, pp.233-243 (1999)
- (2) H.Zohm, G.Gantenbien, G.Giruzzi, S.Gunter, et al., "Experiments on neoclassical tearing mode stabilization by ECCD in ASDEX Upgrade" *Nuclear Fusion* 39, pp.577-580 (1999)