

DEVELOPMENT OF A 40KV SERIES-CONNECTED IGBT SWITCH

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Abstract

A 40kV IGBT SWITCH has been developed for NBI (Neutral Beam Injector) of LHD (Large Helical Device) located at NIFS (National Institute for Fusion Science). The IGBT switch consists of 36 series IGBT devices used for switching and 6 series IGBT devices used for transient-voltage regulation. Since the short-circuit of the load (called as "breakdown") occurs occasionally, fast shut-off and re-feeding functions at the breakdown are required as advanced functions of the IGBT switch in addition to the simple switching DC 40kV-180A.

Also, a protection circuit has been developed against IGBT open mode fault which leads to a severe internal over-voltage situation to the open circuit in the series connection of devices.

Evaluation tests of the IGBT switch were carried out and the IGBT switch showed good performance and characteristics. On/off function at normal load conditions and output regulation function as well as repetitive operation at the short-circuit of the load were confirmed. Furthermore, the open mode fault protection function was also confirmed.

The IGBT switch consists of several IGBT switch units connecting 6 IGBT devices in series. In future, the IGBT switch can be applied for over-100kV-class system by connecting more IGBT switch units in series.

INTRODUCTION

A great amount of research into nuclear fusion has been made at NIFS. LHD is a fusion research device located at NIFS and it is equipped with NBI to heat the plasma.

NBI consists of an ion source, a neutralizer and other components. An ion beam highly accelerated in the ion source is neutralized, and the neutral beam is injected into LHD to heat the plasma. The acceleration power supply (PS) applies high voltage to the plasma grid of the ion source in order to accelerate the ion beam.

A high voltage semiconductor switch is used for the acceleration PS of NBI. A GTO (Gate Turn-Off thyristor) switch has been applied for NBI thus far [1]. This switch consists of many GTO devices connected in series.

Recently, a 40kV IGBT (Insulated Gate Bipolar Transistor) switch has been developed, which consists of 36 series IGBT devices used for switching and 6 series IGBT devices used for transient-voltage regulation, since

IGBT devices have better switching characteristics than GTO devices.

This paper presents circuit configuration, characteristics and test results of the 40kV IGBT switch.

ACCELERATION POWER SUPPLY

Figure 1 shows the schematic diagram of the acceleration PS main circuit and table 1 shows its specifications. The acceleration PS consists of an AC-DC conversion circuit and the IGBT switch.

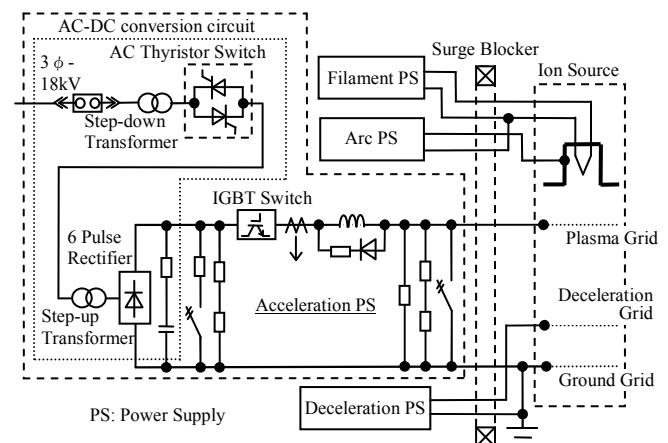


Figure 1: Schematic diagram of the acceleration power supply main circuit.

Table 1: Specifications of the acceleration power supply

Item	Specification
Output	DC 40kV-180A
Pulse Width	10s / 300s repetition
Shut-off Time	less than 100 μ s
Breakdown Restart Time	10ms (max 20 times consecutive)

The function of the IGBT switch is not only switching DC 40kV-180A. Fast shut-off and re-feeding functions are also required.

Since the gap between the plasma grid and the ground grid is very short and very high voltage is applied to the gap, the breakdown occurs occasionally. At the breakdown, the acceleration PS needs to shut off the short-circuit current into the ion source to avoid damage of the plasma grid. On the other hand, the acceleration PS

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also needs to re-feed energy into the ion source 10 ms later after the breakdown from the viewpoint of continuous system operation. These are the reasons why the IGBT switch is required to shut off current fast and to turn on again after the breakdown.

40KV IGBT SWITCH

Figure 2 shows the schematic diagram of the IGBT switch consisting of portions (1) and (2). A module-type IGBT device:CM800HA-66H (3300V-800A) is used. 6 IGBT devices are connected in series in portion (1) while 36 IGBT devices are connected in series in portion (2).

When the IGBT devices in portion (1) are turned off, almost constant voltage is applied to the corresponding nonlinear resistor. Thus, portion (1) regulates output voltage and prevents the ion source from being applied over-voltage in case that the IGBT switch input voltage is higher than the rated voltage. Portion (2) is for main switching function.

In order to withstand high voltage, the IGBT switch consists of series-connected IGBT devices. In case that only one IGBT device is open, the entire voltage is applied to one IGBT device. To avoid this situation, a protection circuit is connected in parallel with each IGBT device. When more than 2200V is applied to an IGBT device (while the maximum voltage normally applied to IGBT device is 2068V), the protection circuit detects the over-voltage situation and makes the acceleration PS stop safely. Furthermore, the protection circuit restricts the IGBT voltage to less than the rated voltage of the IGBT device.

Protection circuits against IGBT short mode fault are connected to every 6 IGBT devices. This circuit detects voltage imbalance among 6 series-connected devices and makes the acceleration PS stop safely.

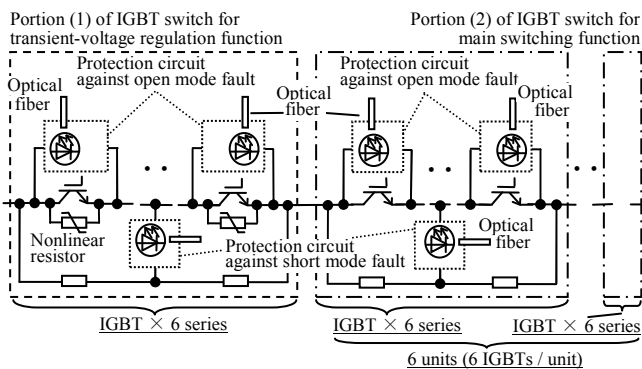


Figure 2: Schematic diagram of the IGBT switch circuit.

Figure 3 shows the external appearance of the IGBT switch. Dimensions are 2574mm in width, 1200mm in depth, and 2433mm in height.

Figure 4 shows the external appearance of the IGBT switch unit which consists of 6 IGBT devices connected in series. Since the IGBT switch is applied for 40kV-class system this time, the 40kV IGBT switch consists of 1 IGBT switch unit with transient-voltage regulation

capability and 6 IGBT switch units for main switching function. In future, IGBT switch can be applied for over-100kV-class system by connecting more units in series.

Portion (1) of IGBT switch for transient-voltage regulation function (IGBT 6 series × 1 unit) Portion (2) of IGBT switch for main switching function (IGBT 6 series × 6 units)

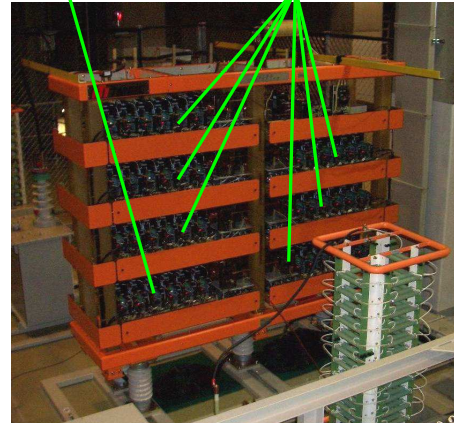


Figure 3: External appearance of the IGBT switch.

6 IGBT devices connected in series



Figure 4: External appearance of the IGBT switch unit.

TEST RESULTS

Output test

This test was carried out on the condition that the input voltage was 40kV and a test load (225 Ω) was connected to the output of the acceleration PS.

Figure 5 shows the waveforms of the output test. It was verified that the IGBT switch can switch 40kV-180A.

Output regulation test

This test was carried out on the condition that the input voltage was 46kV and no load was connected to the output of the acceleration PS.

Figure 6 shows the waveforms of the output regulation test. Although the input voltage was higher than the rated voltage (40kV), the acceleration PS output almost 40kV. It was verified that the output voltage can be regulated by the IGBT switch.

Breakdown restart test

A short-circuit gap (sphere-sphere gap) was connected to the output of the acceleration PS. The distance of the

gap was adjusted so that the gap was short when more than 40kV was applied to the gap. The same situation as the breakdown was made by short-circuit of the gap.

The breakdown restart test was carried out on the most severe condition within the required specifications. Namely, while the input voltage was 40kV, the IGBT switch was turned on and short-circuit of the gap was created at intervals of 10 ms.

Figure 7 shows the waveforms of breakdown restart test. The IGBT switch could turn off at the short-circuit of the gap and could turn on 10 ms later after the short-circuit of the gap. It was verified that the IGBT switch could operate with no problem under a severe noise condition at the breakdown (short-circuit of the gap).

Protection test against IGBT open mode fault

This test was carried out for testing protection circuit against open mode fault. In order to make the situation that the rated input voltage (40kV) was applied to only one IGBT device, the IGBT device was kept open with 40kV input voltage while the others were turned on.

Figure 8 shows the waveforms of the protection test against IGBT open mode fault. The open mode IGBT voltage was increased and reached almost 3kV. However, the protection circuit restricted the IGBT voltage to less than the rated device voltage (3300V). Also, the protection circuit detected fault condition and made the acceleration PS stop safely.

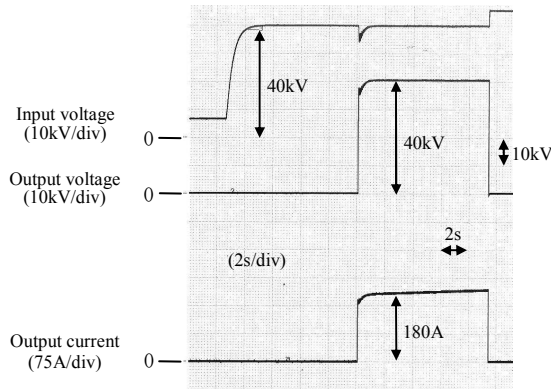


Figure 5: Waveforms of the output test.

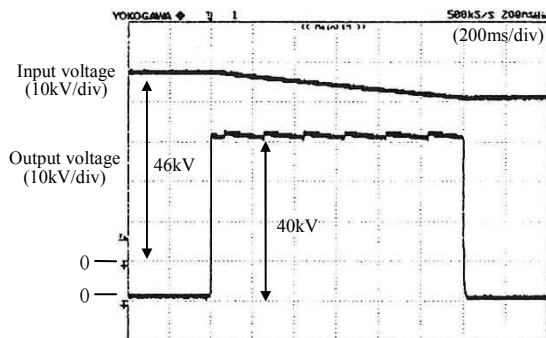


Figure 6: Waveforms of the output regulation test.

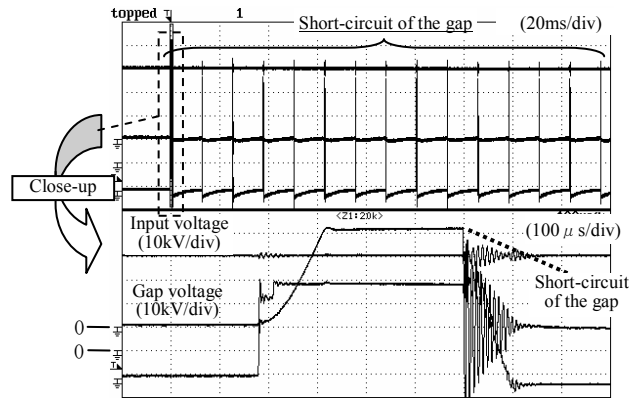


Figure 7: Waveforms of the breakdown restart test.

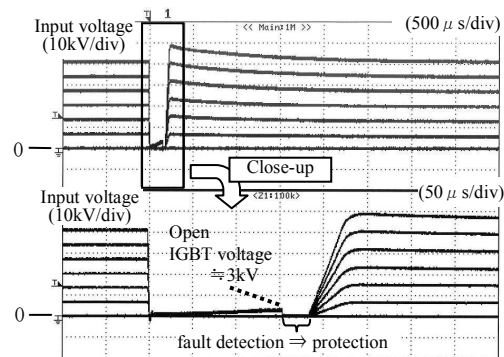


Figure 8: Waveforms of the protection test against IGBT open mode fault.

CONCLUSIONS

A 40kV IGBT switch has been developed, which consists of 36 series IGBT devices used for switching and 6 series IGBT devices used for transient-voltage regulation. Also, a protection circuit has been developed against IGBT open mode fault which leads to a severe internal over-voltage situation within series-connected devices.

Evaluation tests were carried out and good test results were obtained regarding IGBT switch characteristics, on/off function at normal load conditions and output regulation function as well as repetitive operation at the short-circuit of the load. Furthermore, the open mode fault protection function was also confirmed.

Through developing the 40kV IGBT switch, a basic IGBT switch unit has been developed. In future, IGBT switch can be applied for over-100kV-class system by connecting more IGBT switch units in series.

REFERENCES

[1] Mamoru Matsuoka et al. , “Development of Acceleration Power Supplies of a Neutral Beam Injection System Using GTO Switches with Transient-Voltage Regulation Capability”, IEEJ Transactions on Power and Energy Vol.112-B No.11, 1992, pp1035 – 1044.