HIGHLY-PERFORMED POWER SUPPLY USING IGBT FOR SYNCHROTRON MAGNETS

M. Muto#, Y. Mori, K. Niki, KEK, Tsukuba, Japan
S. Koseki, H. Kubo, M. Toriyama, Hitachi Co.Ltd, Hitachi, Japan

Abstract

A new power supply using IGBT is developed in order to investigate the feasibility of use of IGBT to large-scale power supplies for synchrotron magnets. The power supply is constructed with a converter and a chopper blocks, which are made up of IGBT modules. The active peak power and the maximum output current are 1 MW and 3000A. The preliminary tests showed the current ripple is a few x 10^{-6} with only a very small-size passive filter. The paper describes the design parameters of the power supply and the test results in detail.

1 INTRODUCTION

We have developed a new power supply using IGBT to investigate the feasibility of use of IGBT as a power converter element to large-scale power supplies for magnets of synchrotrons such as the JHF main ring [1]. By using IGBT, it becomes possible to construct a power supply basically not generating a reactive power in spite of that the power supply is operated with a trapezoidal output current wave-form. Furthermore, the very high switching frequency makes it easy to control the output current shape with very small tracking error and to regulate the current ripple to be very low level without a large-scale passive filter or an active filter.

The power supply has been designed so as to generate a trapezoidal wave-form output current with the active peak power of 1 MW and the maximum current of 3000 A. Additionally, it is operated as a dc power supply with the peak current of 3000 A. A part of power converter consists of a converter block and a chopper block, which are made up of IGBT modules. The switching frequency of the IGBT module is 8 kHz per each, and the ripple frequency of the output current is 128 kHz.

The preliminary tests with the output current shape based on the JHF excitation-pattern [1] showed that the current ripple at the flat-top of the excitation being a few x 10^{-6} with only a very small-size passive filter, the current stability being less than 5×10^{-5} and the tracking error being less than 3×10^{-4}. The power supply has been operated successfully to study the field quality of the R&D magnet of the JHF 50-GeV main ring [2].

2 CONSTITUTION OF THE POWER SUPPLY

Figure 1 shows the skeleton diagram of the power supply. To realize a very large dynamic range of the output current, the converter-chopper combination method is adopted. The main design parameters of the power supply is summarized

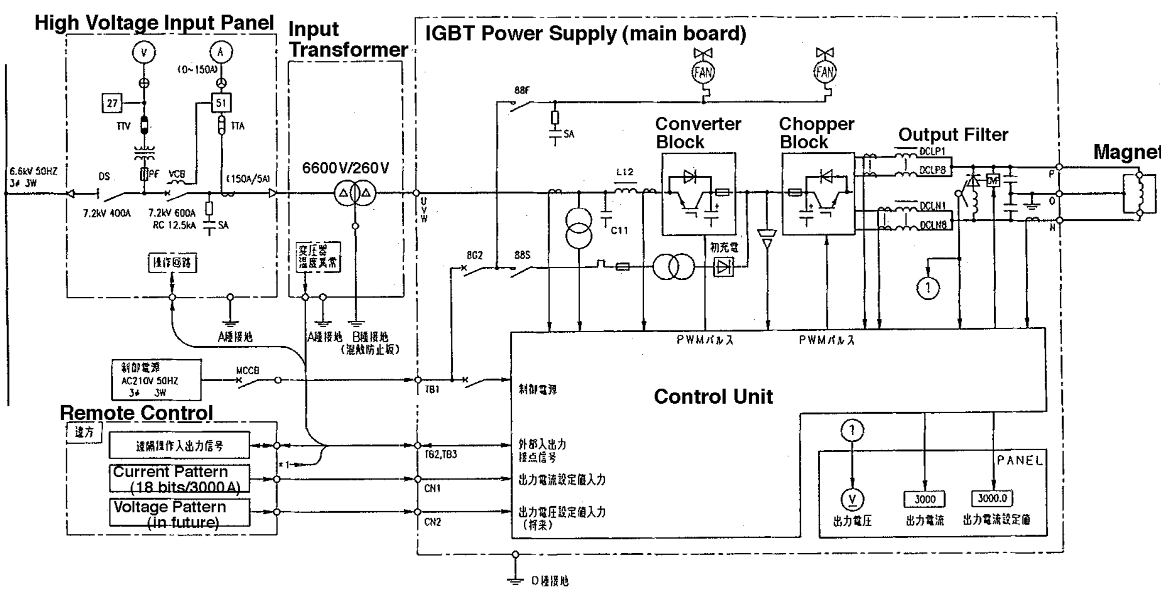

Figure 1: Skeleton diagram of the power supply.

E-mail: masayuki.muto@kek.jp

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in Table 1, and the typical output current pattern is shown in Figure 2.

Table 1: Main parameters of the power supply.

input voltage	AC 6600 V (or 3300 V)
converter element	IGBT
method	combination of converter-chopper
operation mode	trapezoidal (peak 1 MW), and DC (max. 3000A)
output current	100 ~ 3000 A
output voltage	0 ~ +- 333V
current ripple	10^{-5} (for H=20 mH) (required) 10^{-6} (expected)
stability	10^{-4}
tracking error*	10^{-3}

* tracking error = (Iactual - Ireference)/Ireference-max

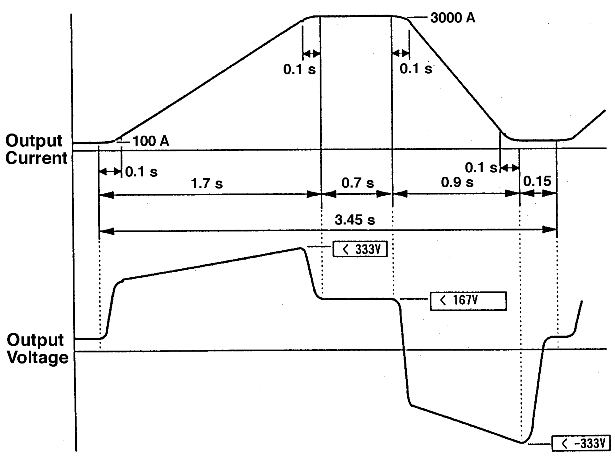

Figure 2: Typical output pattern of the power supply.

2.1 IGBT Module

The converter and chopper blocks are constructed with IGBT modules; 9 modules for the converter and 16 modules for the chopper, and each module is constructed with 5 IGBT packages (2 IGBTs in each package). The maximum rates of voltage and current of the IGBT are 1200 V and 300 A, respectively. Figure 3 shows the circuit diagram of the IGBT module. The specification of the module is the same for the converter and chopper blocks, and it is connected oppositely corresponding to converter or chopper as shown in Figures 1 and 2.

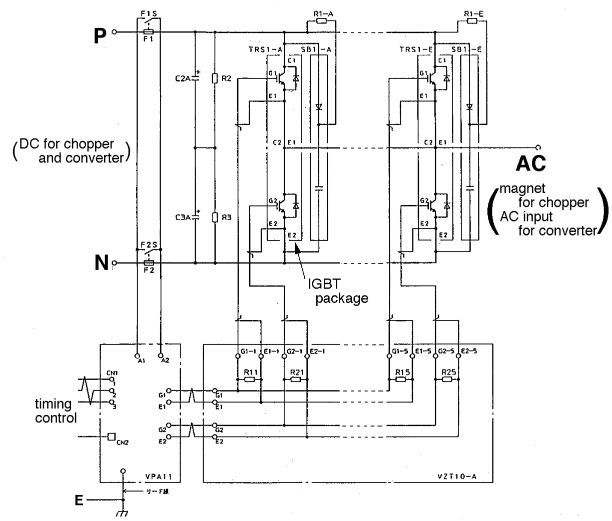

Figure 3: Circuit diagram of the IGBT module

The converter is operated with the switching frequency of 5 kHz for each phase, to convert AC power to DC power with the output voltage of about 410 Vdc (205 Vdc for the case of 3300 V input voltage), and to regulate the input power-factor near unity during operation.

The 16 modules for the chopper block are divided into two groups (P and N), and the 8 modules for each group are connected in parallel, with a small reactor (DCLP or DCLN, shown in Figure 1) for each module. This small reactor forms passive filter with condensers of downstream, whose cut-off frequency is set to be 1.8 kHz. The switching frequency of the chopper module is 8 kHz, then the output ripple frequency becomes 128 kHz (8 x 16 modules). This is enable us to make the control speed fast and the size of output filter very small. Finally, the only passive filter described above is equipped as an output filter and an active filter is not employed.

3 TEST RESULTS

The power supply was tested with the input voltage of only 3300 V, because the 6600 V power line was not available for the R&D facility at present. As a test load, the R&D bending magnet of the JHF 50-GeV main ring (L=8 mH, R=4.3 mΩ) was used.

3.1 Input Characteristics

The power factor and harmonic current of the input power was measured with the condition of trapezoidal output current whose peak current was 3000 A, peak power was 267 kW and ramping up ratio was 9700 A/s. The power factor was nearly unity above the output power level of 150 kW and about 0.87 at the power of 100 kW. The total harmonic current (rms.) was about 4.1%.

3.2 Output Current Ripple

A current ripple was calculated from the voltage ripple measured at the output terminal of the power supply.

Figure 4 shows the spectrum pattern of the terminal voltage when the power supply was operated with the output current of DC 3000 A, and Table 2 shows the current ripple calculated from the voltage ripple at the frequency range of 50 ~ 600 Hz.

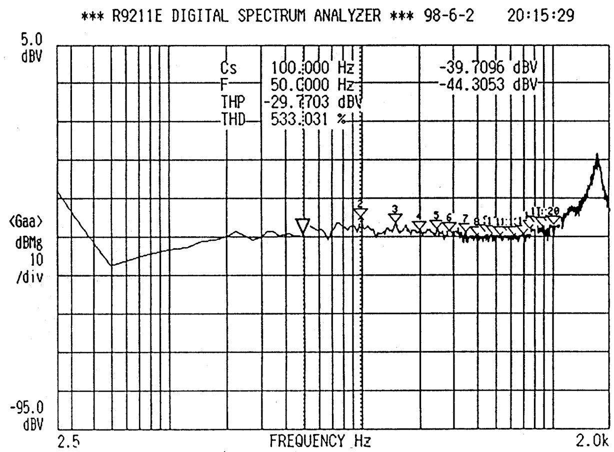

Figure 4: Spectrum distribution of voltage ripple.

Table 2: Current ripple measured with DC 3000 A.

n	f (Hz)	voltage ripple (meas) dBV(0dBV=1Vrms)		current ripple (cal) (20mH)
		dBR	dBV	
1	50	———	-44.3053	9.14069E-07
2	100	4.59569	-39.7096	7.75771E-07
3	150	3.25764	-41.0477	4.43343E-07
4	200	1.35123	-42.9541	2.66981E-07
5	250	1.77125	-42.5341	2.24167E-07
6	300	1.13079	-43.1745	1.73527E-07
7	350	0.90861	-43.3967	1.44981E-07
8	400	0.09316	-44.2121	1.15491E-07
9	450	0.49535	-43.8100	1.07524E-07
10	500	0.15114	-44.1542	9.30113E-08
11	550	0.00755	-44.2978	8.31694E-08
12	600	-0.12508	-44.4304	7.50833E-08

The current ripple at the frequency of 8 kHz and 64 kHz (due to the switching frequency of the chopper module) was 8.28 x 10^{-8} and 1.07 x 10^{-7}, respectively. On the other hand, at the frequency of 1.8 kHz, which was the cut-off frequency of the output filter, was 6.4 x 10^{-7}.

The current ripple when the power supply was operated with the output of trapezoidal wave-form shown in Figure 2 was also measured. Table 3 shows the calculated results of the current ripple. At the frequency range of 50 ~ 300 Hz, it becomes larger than that of DC operation listed in Table 2 by factor 2 ~ 3.

Table 3: Current ripple measured with the output of trapezoidal wave-form.

f(Hz)	dBv	ripple
50	-33.9046	3.027 x10^{-6}
100	-36.3797	1.138
150	-29.2714	1.720
200	-30.5068	1.119
250	-28.3780	1.144
300	-31.6048	6.574 x10^{-7}
350	-35.9082	3.433

3.4 Tracking Error

Figure 5 shows the tracking error which defined in Table 1. It was less than 3 x 10^{-4} during ramping-up period of the pattern. The trapezoidal output current wave-form, whose peak current is 3000 A, is also clearly seen.

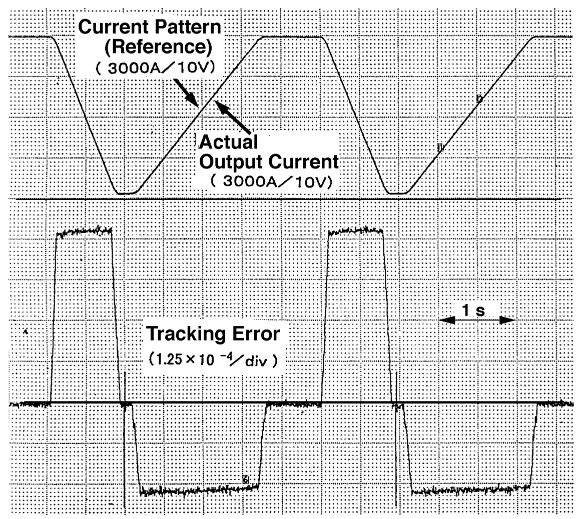

Figure 5: Tracking error and trapezoidal output current wave-form.

4 CONCLUSION

We constructed a new power supply with the output peak power of 1 MW by using IGBT. The test results showed that it might be possible to construct a power supply with the peak power of around 10 MW level with using only IGBT. The power supply developed here has been operated successfully to study the field quality of the R&D magnet of the JHF 50-GeV main ring now, and will be operated for mass field-measurements in future.

5 REFERENCES

[1] JHF Project Office, "JHF ACCELERATOR DESIGN STUDY REPORT", KEK Report 97-16 (JHF-97-10), p2.4-1, (1998)

[2] M.Muto et al., "Magnets and Power Supply System of JHF 50-GeV Main Ring" APAC98, KEK, Tsukuba, (1998)