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NEW POWER SUPPLY OF MAIN MAGNETS FOR J-PARC MAIN RING UPGRADE

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Abstract

It is planned that the proton beam power provided to experimental facilities increase with shortening repetition period in J-PARC Main Ring (MR). As the shorten repetition period, the replacement of the power converters for main magnets in J-PARC MR is necessary to cope with issues such as power fluctuation of the main grid and increase of the output voltage. We have considered and developed the power converters with a 10 MW cass which have the capacitor banks with the large capacitance. In the end of 2017, the first new power converter for a bending magnets family, which is the largest power converter in this upgrade plan, was installed in J-PARC site and the power test is ongoing using a dummy and the actual load. In this report, the first new power converter for a bending magnets family in J-PARC MR is reported including the test results.

INTRODUCTION

J-PARC MR is a high intensity proton synchrotron for the particle and nuclear physics. The proton beam is accelerated from 3 GeV to 30 GeV in the MR and provided to experimental facilities [1]. Currently the intensity of the extraction beam has reached 500 kW. However, We still need to increase the beam intensity to over a megawatts (MW) to maintain the international competitiveness. One of the promising solutions for increasing the beam power is to shorten the repetition period from current rating 2.48 sec to 1.3 sec.

The output voltage of the power converter is described as

$$V = RI + L\frac{dI}{dt}, \tag{1}$$

where R, L and I are the resistance, the inductance and the driving current of the magnets, respectively. For faster repetition rate, the driving current of electromagnets must be ramped up/down faster with the higher voltage power converters. The output power of the power converters also becomes higher and the power variation of the electric system is expected to increase. Therefore the new power converters need the energy storage system to suppress the power variation. On the other hands, for the stable operation of the J-PARC MR, precise output current control of the power converters is required. Both of the tracking error and the current ripple of the power converters for the main magnets should be suppressed at a level of 100 ppm. Consequently, we have planned to develop new power converters for the main magnets, such as bending, quadrupole and sextupole, and replace the present power converters with the new ones. The ratings and number of main magnet power converters required from the J-PARC MR upgrade are shown in Table 1. Several identical power converters are also needed.

Table 1: List of Current and Voltage Rated of New Power Converters and Required Number of Power Converters for Upgrade

Magnet family	Flat Bottom Current [A]	Flat Top Current [A]	Output Voltage at 1.3 sec repetition (Peak) [kV]	Number of power converters
Bending	190	1570	6.0	6
Large quadrupole	80	1000	7.0	4
Small quadrupole	70	1000	1.5	7
Sextupole	20	200	0.8	3

The design of the new power converters and the controllers has been finished. And a power converter for a small quadrupole magnet family has been already finished test and installation at 2016 [2] and it has been also used user operation. The new power converter for a bending magnet family (BMPS) has been manufactured and installed in the J-PARC site at the end of 2017.

NEW POWER CONVERTER FOR A BENDING MAGNET FAMILY

The new BMPS has the output power of 10 MVA. The schematic circuit and pictures are shown in Fig. 1 and Fig. 2. The new BMPS consists of 2.5 MVA transformer, 2 series of 3 phase AC/DC converter, capacitor banks, 6 series of choppers and output filter. The capacitor bank has a role of energy storage for suppressing power variation in main grid. The capacitance of each banks is 0.48 F (0.7 MJ) respectively [3].

Main Circuit

The new BMPS is adopted the floating capacitor method [4]. It is designed to be able to reduce the number of rectifier circuits significantly and eliminate the rectifier circuit of high potential. The each of six choppers is connected a capacitor bank. There are two types capacitor banks in the new BMPS. One is the capacitor bank connecting to rectifier for charging, called charging capacitor. The chopper con-

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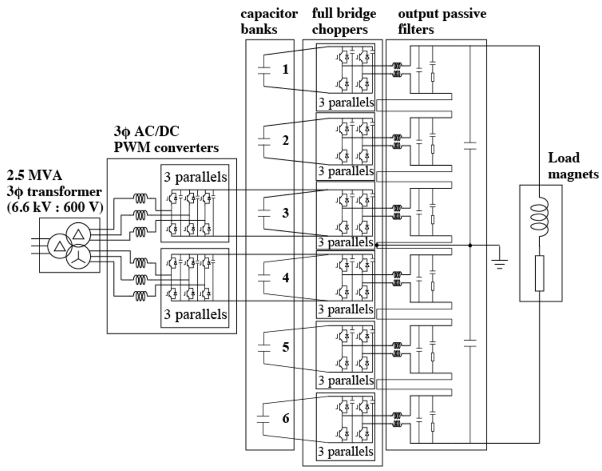

Figure 1: Schematic view of power converter for the bending magnet family in J-PARC MR.

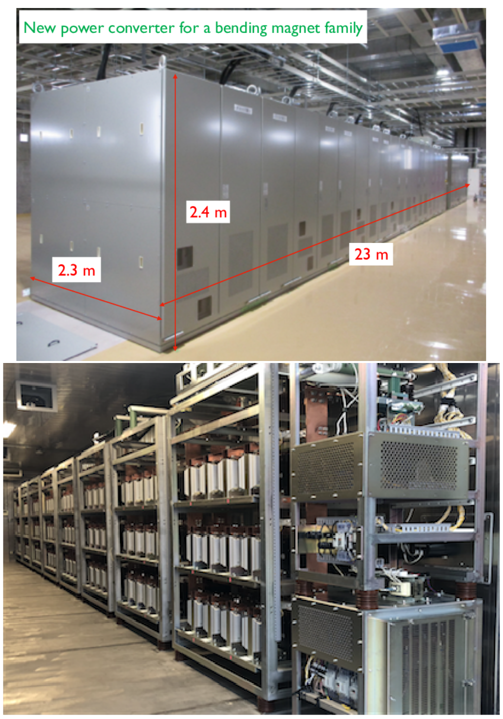

Figure 2: Pictures of power converters (upper) and a capacitor bank installed in a container (bottom) for the bending magnet family in J-PARC MR.

necting the charging capacitor woks compensation of loss energy in the load and the circuit. The other is the capacitor bank connecting only chopper, called floating capacitor. The chopper connecting floating capacitor is only transferred the magnetic energy between the capacitor bank and the load. Therefore the floating capacitor is only charged via the load.

Controller

Considering reproducibility in the mass-production and the facilitation of the control algorithm, the digital control system is adopted. The controller [5] consists of four main parts: the current measuring device, the feedback control system, the gate pulse generator for the power units and the slow control system, whose rules are summarizing alarms, managing sequence and failure protection, as shown in Fig. 3. Analog components are included only in the current measuring device while the other three parts are purely digital. The connection of main circuit and the controller is also isolated to eliminate the contamination of noise from the main circuit.

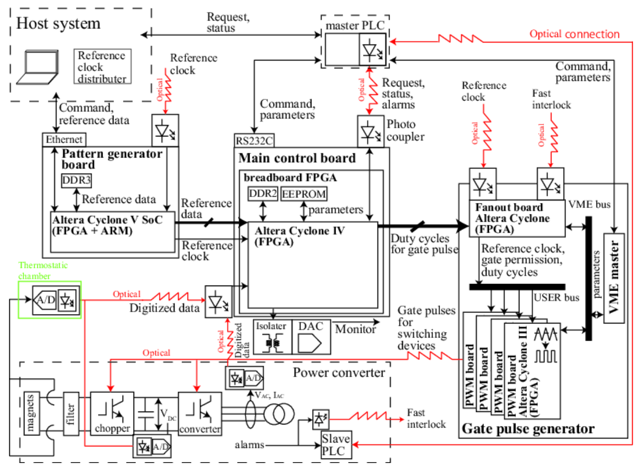

Figure 3: Overview of the controller.

TEST OPERATION

The new BMPS has been tested with the actual load which is a bending magnet family in J-PARC MR. The total inductance and resistance of the actual load are 1.47 H and 0.76 Ω, respectively. The current pattern is proportional to the momentum of beam which changes from 3.825 GeV/c to 30.924 GeV/c. The rated current of this power converter at flat-bottom and flat-top are about 190 A and 1570 A which are defined by the minimum and maximum beam momentum. In addition, two operating modes of the beam extraction are available in the J-PARC MR. One is the fast extraction. In this extraction mode, the beam is extracted immediately after the beam acceleration as shown in Fig. 4. The other is slow extraction. As the beam is continuously and slowly extracted from MR during a few second, the output current is kept the maximum during extraction (flat-top) as shown in Fig. 4. As the instantaneous rate of extraction beam is severe in the user experiment, the precise control of output current on the order of parts per million is required for the flatness in time structure of extraction beam.

The measured output current, voltage, voltage of charging capacitors ($V_{Charging}$) and voltage of the floating capacitors ($V_{Floating}$) are shown in Fig. 5. The current pattern for the SX mode is used in this test but this pattern is also equivalent to 1.3 sec repetition in the FX mode. The new BMPS is driven using capacitive energy n the ramping-up period of current pattern, and the capacitor banks are charged with the magnetic energy in the ramping-down period of current

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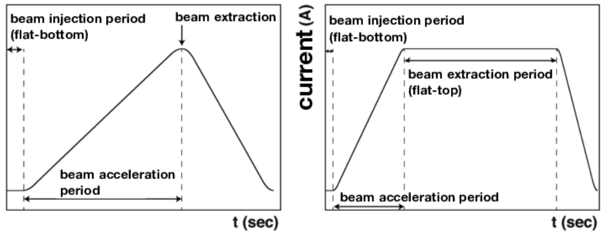

Figure 4: Schematic view of output current pattern in FX (left) and SX (right) mode.

pattern. Figure 6 shows the measured input and output power. The output power has large variation about 14 MV but the deviation of input power is only 2 MVA. This result shows the successful of the power control with the capacitor banks.

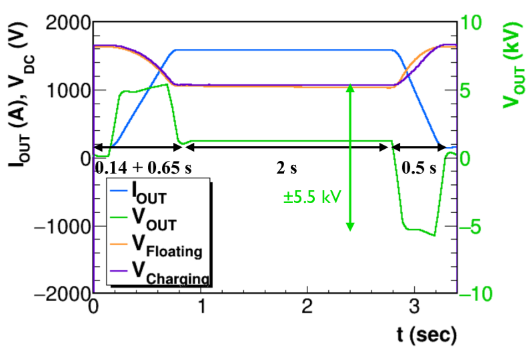

Figure 5: Measured output current, voltage and voltages in charging and floating capacitor in the test with the SX pattern.

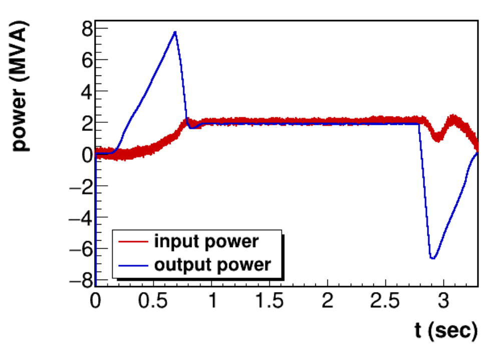

Figure 6: Measured input and output power.

To check the precision of the current regulation at the flat-top, a frequency domain spectrum of the fractional current deviation in comparison with the present BMPS in J-PARC MR is shown in Fig. 7. The current deviation was measured to be much less than 10^{-5} in all frequencies except for the switching frequency (2 kHz) and its harmonics. These frequency components are not problem for our applications because the beam ducts of J-PARC MR shield the magnetic fields with frequencies higher than 1 kHz by a factor of approximately 10. The current deviation is reduced by a factor of approximately 10 in the low frequency region in the new BMPS.

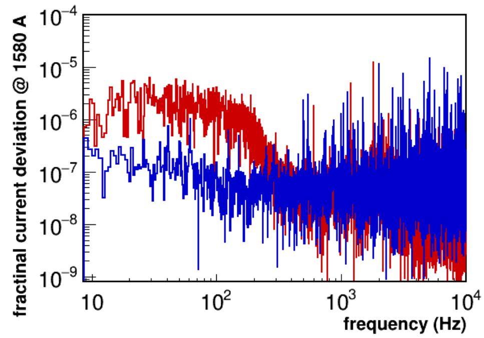

Figure 7: Spectrums of the fractional current deviation in the new BMPS and the present BMPS (red).

CONCLUSION

The upgrade for increasing the beam power in the J-PARC MR is progressing. The new power converters for the main magnets in J-PARC MR that realizes the operation with the high repetition rate have been developed. The new BMPS has been finished manufacturing and the commissioning of new BMPS is on-going. We succeeded in the demonstration of the operation with rated current and current pattern with 1.3 sec repetition in FX mode equivalent, and the demonstration of the energy storage scheme with the capacitor banks. In addition, We confirmed that the new BMPS regulates current at a precision of less than 10^{-5}.

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