COMPENSATION OF LOAD FLUCTUATION OF POWER SUPPLY SYSTEM FOR LARGE ACCELERATOR USING SMES

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Abstract

In J-PARC 50GeV synchrotron, peak active power and the dissipation power of main magnets are estimated to be about 135MW and 37MW, respectively. Super Conducting Magnetic Energy Storage(SMES) is one of candidates to compensate these large load and line voltage fluctuation. Study on circuit configuration of the power supply with SMES will be discussed. Plan of experiment is also described.

INTRODUCTION

The J-PARC Project is under progress as the joint project by the Japan Atomic Energy Research Institute (JAERI) and the High Energy Accelerator Research Organization (KEK). The facility is located at the JAERI Tokai site and comprises a 600-MeV linac (200MeV in the phase I), a 3-GeV rapid-cycling synchrotron (RCS), and a 50-GeV synchrotron (MR). The 50-GeV synchrotron main ring comprises 96 bending magnets, 216 quadrupole magnets, 72 sextupole magnets and 186 steering magnets. The power supply system for the magnets of the 50-GeV synchrotron is made up of a large number of power supplies, one is for the bending magnets, 11 ones for the families of the quadrupole magnets, 3 ones for the families of the sextupole magnets and 186 ones for the steering magnets. These power supplies are operated with an excitation pattern of trapezoidal wave form as shown in Fig.1. The total amounts of active power of these power supplies become about +105MW~ -66.0MW in peak with only cable loss for 50-GeV operation[1].

As well known, conventional thyristor rectifiers with a high power and trapezoidal dc side output current usually generates a very large cyclic variation of reactive power and raises unallowable line voltage fluctuation. In order to overcome this problem, power converters using IGBT or IEGT are investigated for the power supply of the J-PARC project. By using power semiconductor devices of this type, it is possible to construct power supplies with the characteristics of unity power factor operation. The line voltage fluctuation estimated is about +2.5%~-2.5% for 50GeV operation, if the reactive power is compensated perfectly. However, this fluctuation is not acceptable for the power line. Then, some active power compensation device is necessary for 50GeV operation. At this present, adjustable speed flywheel generation system to flatten the very large power swing has been designed[1]. In the phase I, 50GeV synchrotron should be operated with on energy of 30GeV or 40GeV at highest with out flywheel. This paper shows the study on application of superconducting magnetic energy storage (SMES) for this purpose. In the case of SMES, it is possible to connect the SMES magnet at the dc side of the synchrotron power supply and exchange energy between the accelerator magnet and the SMES magnet. Sveral circuit configurations are proposed and typical simulation result using is presented in this paper.

CIRCUIT CONFIGURATION OF POWER SUPPLY

The largest power supply for the synchrotron is for the bending magnets. Other power supplies for quadrupole magnets, sextupole magnets and steering magnets are small and do not affect line voltage fluctuation. Requirements for the power supply of the bending magnet is shown in TABLE1. Current pattern of the bending magnet is shown in Fig.1.

TABLE I

Requirements for Power Supply of Bending Magnet

Excitation dc current	202A ~ 3015A
Peak dc voltage	+25.2kV, -32.5kV
Active power (peak)	72.5MW, -54.4MW
Coil inductance	104mH/coil
Coil resistance	45mΩ/coil
Number of coils	96

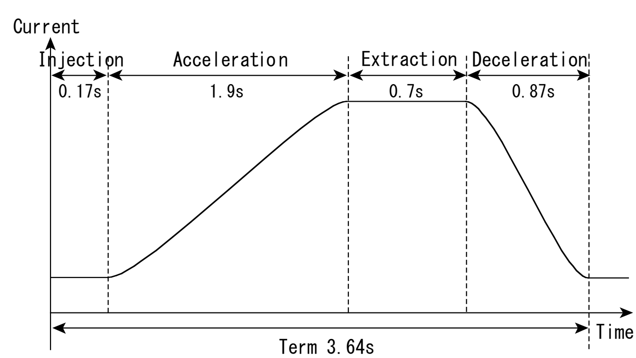


Fig.1. Typical excitation current pattern of the bending magnet for 50-GeV operation.

The power supply with SMES proposed in this paper is for the bending magnets.

Fig.2 shows various configuration of the power supply. Fig.2(a) shows the system using line commutated ac/dc converter. In this case, SMES should compensate both active and reactive power variation. As a result, the power rating of the SMES becomes the largest. The configuration shown in Fig.2(b) shows the system using forced commutated ac/dc power converter using IGBT and IEGT. In this case, the magnet power supply can operate at unity power factor. As a result, SMES compensates only active power variation. But there is power exchange through two ac/dc power converters, resulting with high power supply cost and losses. The configuration shown in Fig.2(c) uses forced commutated ac/dc power converter and dc type SMES. In this case, power rating of the ac/dc converter for magnet power supply can be reduced, resulting with the reduced cost of the total system. The system shown in Fig.2(c) is the proposed system and studied hereinafter.

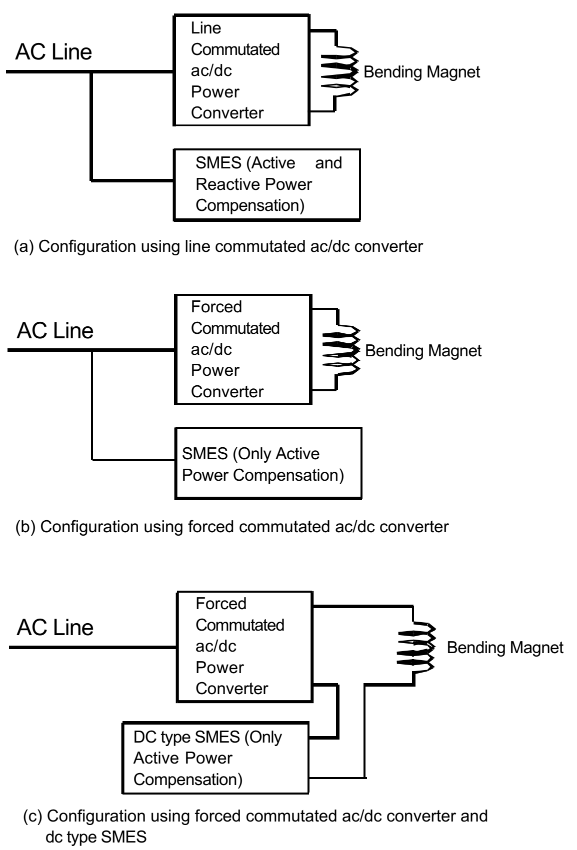


Fig.2. Various configuration of magnet power supply with SMES.

The power supply of the bending magnets is divided into six separated power units, because the electric power rate for the bending magnet is too large to construct a power supply as one unit. By this method, the power rating for one power unit is reduced to the possible level about 5 kV and 10MW. Fig.3 shows connection scheme between the power units and the bending magnets. As seen in the figure, the 96 bending magnets are divided into three groups and both upper and lower coil of the magnet are connected separately by series in each group, and connected with the power units in turn so as to make one excitation loop. The simulation was done by the configuration of one power unit, which is 1/6 of the bending magnet power supply. Each of the power unit is composed of a current source ac/dc converter and SMES. The 40GeV operation can be carried out by the configuration without SMES, because of the acceptable voltage fluctuation in the case.

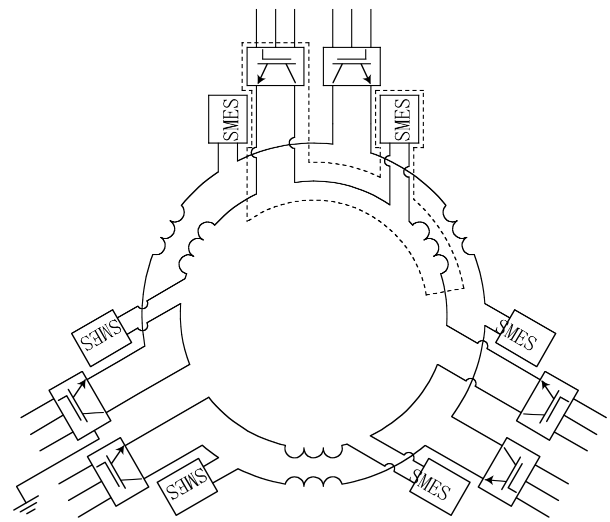


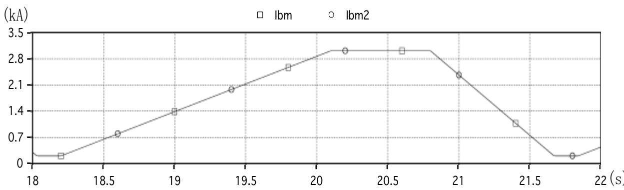
Fig.3. Connection of power supply of the bending magnets with SMES.

SIMULATION RESULTS

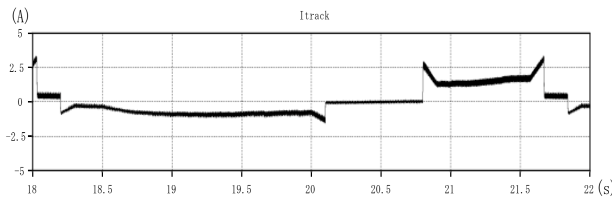
Fig.4 shows the simulation results for the 1/6 of the bending magnet power supply, using PSCAD/EMTDC software. The current of the bending magnet was controlled with the low tracking error. The reactive power was controlled at almost constant value, which is due to the capacitor of the ac side filter. The power variation of the ac/dc converter during the operation cycle was about 11 MW. The average current of the SMES coil is controlled to be constant except the initial transient. The charging and discharging energy of the SMES was about 5MJ.

Fig.5 shows the voltage and current waveform ac source. In this case, the phase difference between the voltage and the corresponding phase current is almost 180 degree, which shows low reactive power. The current waveform is almost sinusoidal.

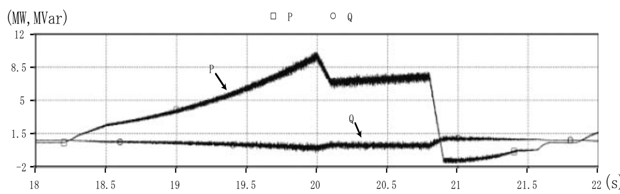
The voltage fluctuation of ac line considering the total system was also calculated and the calculated results are shown in Fig.6. The calculated voltage fluctuation was acceptable for the system. Detailed simulation and the control system was presented in the reference[2].



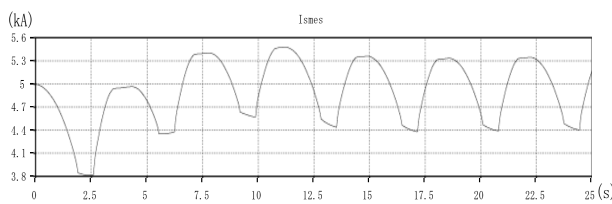
(a) Current of bending magnet (Reference and output are almost same)



(b) Tracking error of bending magnet current

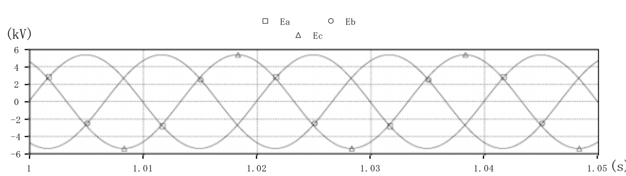


(c) Active (P) and reactive (Q) power of the ac/dc converter

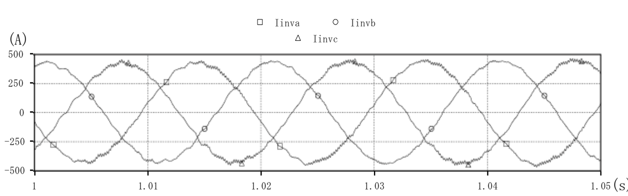


(d) Current of SMES coil

Fig.4. Simulation results of the proposed system.

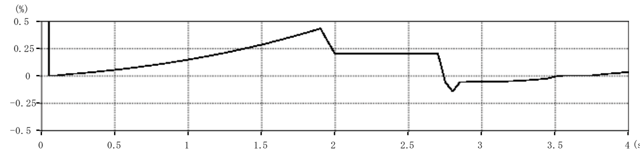


(a) AC source voltage

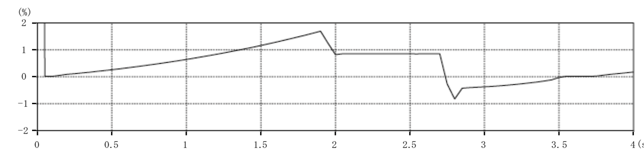


(b) AC source current

Fig.5. AC source side voltage and current waveforms.



(a) 154kV line



(b) 66kV line

Fig.6. Calculated line voltage fluctuation.

CONCLUSIONS

The power supply system using SMES for the J-PARC 50-GeV main ring was proposed and the fundamental characteristics of the configuration as shown in Fig.2(c) have been calculated. For the configuration of Figures2(a) and 2(b), the flywheel system gives the almost same effect, but Fig.2(c) system has advantages over the flywheel system, because of the dc side coupling between the energy storage device and the accelerator coil, resulting with the reduced ac/dc converter power rating. Then, the running cost of the electric power will be less than that of original design as 1/5. The proposed system can be applicable for the extension of the system from the initial 40-GeV operation without energy storage device.

Authors and colleagues are now considering to perform the SMES experiment at the KEK-12GeV PS extraction septum magnet power supply, of which total power in 1MW, with using the existing ESK[3] system under collaboration with KYUSHU Electric Power Company.

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[1] Accelerator Technical Design Report for High-Intensity Proton Accelerator Facility Project (http://hadron.kek.jp/member/onishi/tdr/index.html).

[2] T.Ise, et.al., to be printed in IEEE Transaction on Applied Super conductivity

[3] T.Imayoshi, et.al., IEEE Transaction on Applied Super conductivity, 7(1997)844
KEPCO Research Laboratory's Catalogue, "SMES Field Test"