MAGNET POWER SUPPLY WITH SMES IN THE DC LINK FOR LARGE SCALE ACCELERATORS

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Abstract

The power supply for large scale accelerator magnets draws large amount of power from utility network. For example, the JHF 50-GeV main ring will require 104MW of total active power and 28.8MW of dissipation power by estimation. Moreover, the charging and discharging cycle is repeated with 3.64s of the cycle time at the initial operation, and the repeating frequency will be raised up by twice in future. In this paper, the power supply using SMES is proposed. The power supply can absorb the fluctuation of active and reactive power caused by charging and discharging the synchrotron magnet. The system is composed of current source ac/dc converter, chopper circuits and superconducting magnets. The chopper circuits for superconducting magnets and synchrotron magnets can be connected to the same dc bus of the power supply and this feature can reduce the power rating of ac/dc converters.

INTRODUCTION

The Japan Hadron Facility (JHF) 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 system has the 50-GeV synchrotron main ring consists of 96 bending magnets, 216 quadrupole magnets, 72 sextupole magnets and 189 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 189 ones for the steering magnets. The total amounts of active power of these power supplies become about +104MW~ -69.0MW in peak without cable loss and other losses 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 JHF 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. This fluctuation is not acceptable for power line. As a result, some active power compensation device is necessary for 50GeV operation. Already, adjustable speed flywheel generation system to flatten the very large power swing has been studied as a candidate[1]. This paper shows the study on application of superconducting magnetic energy storage (SMES) for the 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. The circuit configuration, control system, and some simulation results using PSCAD/EMTDC software are presented in this paper.

THE MAIN CIRCUIT OF POWER SUPPLY

Requirement for the 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 Table 1. Charging and discharging current pattern of the bending magnet is shown in Fig.1.

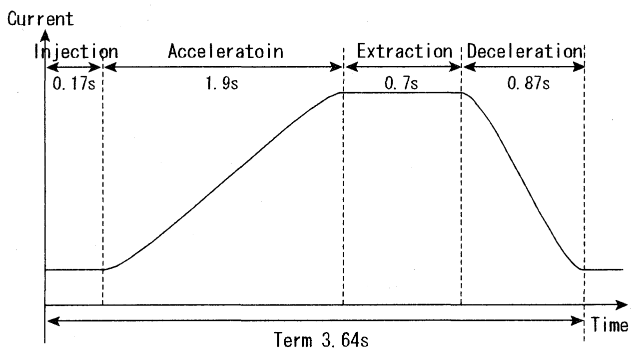
The power supply with SMES proposed in this paper is for the bending magnets.

Circuit Configuration

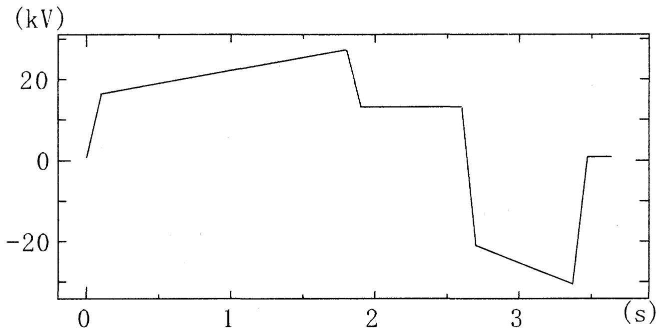
Fig.2 shows various configuration of the power supply. Fig.2(a) shows the system using line commutated ac/dc converter. In this case, SMES should compensate both active and reactive power variation. As a result, the power rating of the SMES becomes the largest. The configuration shown in Fig.2(b) shows 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.

Table 1:Requirements For Power Supply Of Bending Magnet

Excitation dc current	202A ~ 3015A
Peak dc voltage	+24.7kV, -32.6kV
Active power (peak)	71.1MW, -55.3MW
Coil inductance	104mH/coil
Coil resistance	45mΩ/coil
Number of coils	96



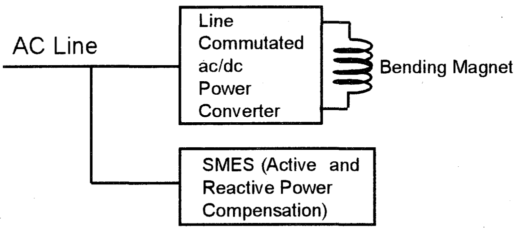
(a) Current pattern



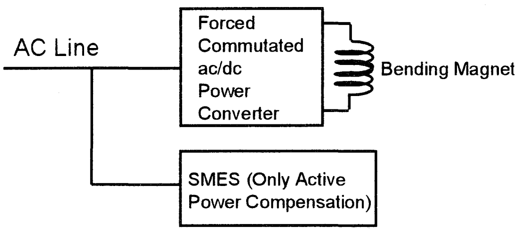
(b) Voltage pattern

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

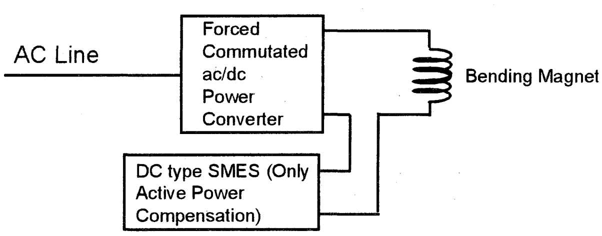
The power supply of the bending magnets is divided into six separated power units, because the electric power rate for the bending magnet is too large to construct a power supply as one unit. By this method, the power rating for one power unit is reduced to the possible level about 5 kV and 10MW. Fig.3 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 configuration of one power unit, which is 1/6 of the bending magnet power supply, is shown in Fig.4. 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.



(a) Configuration using line commutated ac/dc converter



(b) Configuration using forced commutated ac/dc converter



(c) Configuration using forced commutated ac/dc converter and dc type SMES

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

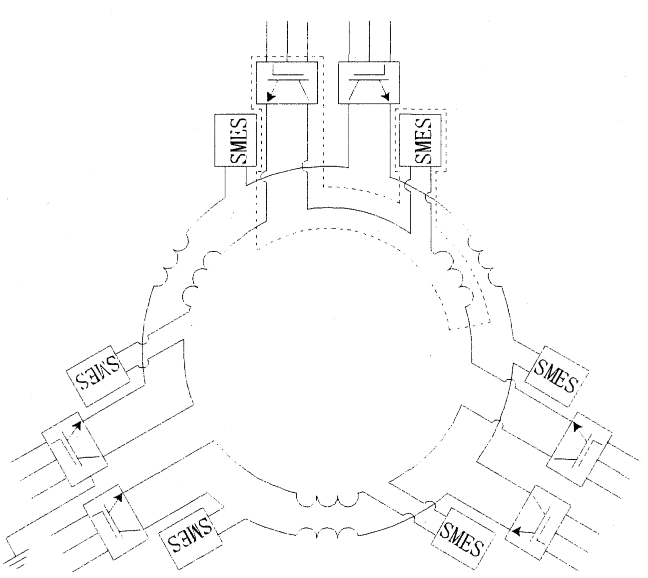


Fig.3: Connection of power supply of the bending magnets with SMES.

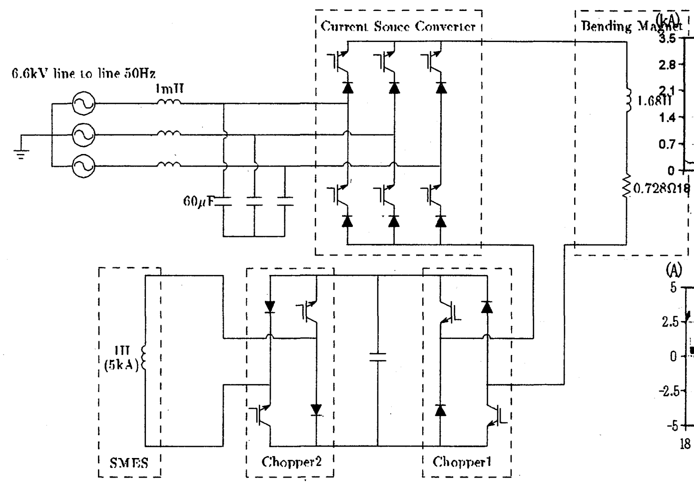


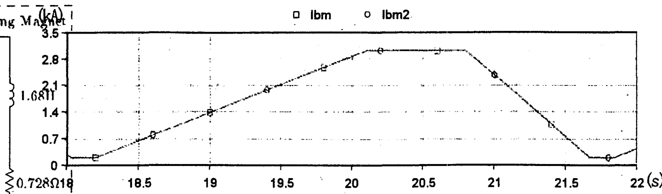
Fig.4: Connection of one unit power supply.

SIMULATION RESULTS

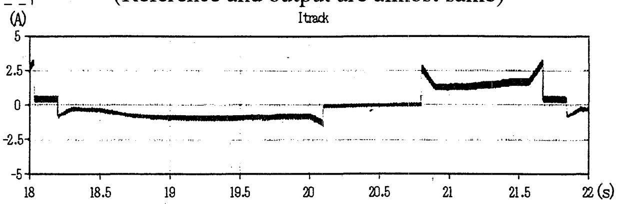
Fig.5 shows the simulation results using PSCAD/EMTDC software. The current of the bending magnet was controlled with the low tracking error. The reactive power was controlled at almost constant value, which is due to the capacitor of the ac side filter. The power variation of the ac/dc converter during the operation cycle was about 11 MW. As the Fig.5 is the simulation of the 1/6 of the total system, the total variation of active power will be 66MW, which is almost half of the power variation of 50-GeV operation, which is calculated to be 126.4MW (71.1 - (-55.3) MW) from Table 1. 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.

Although the voltage and current waveforms are not shown in this paper, the phase difference between the voltage and the phase current was almost 0 or 180 degree during the simulation, which shows low reactive power. The current waveform was almost sinusoidal, which shows low harmonic current.

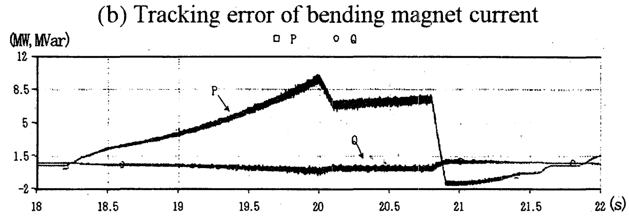
Fig.6 shows the impedance map of the system, where the JHF synchrotron will be installed. The voltage fluctuation of ac line considering the total system was also calculated using PSCAD/EMTDC software. The calculated results are shown in Fig.7. The calculated voltage fluctuation is acceptable for the system.



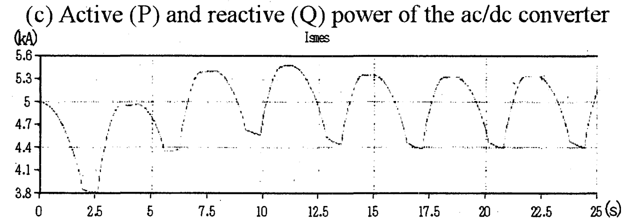
(a) Current of bending magnet
(Reference and output are almost same)



(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.5: Simulation results of the proposed system.

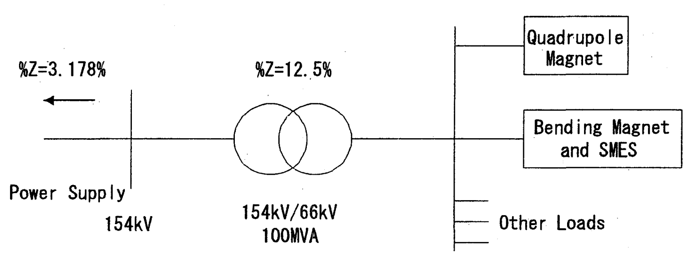
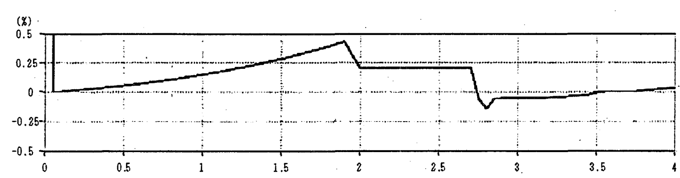


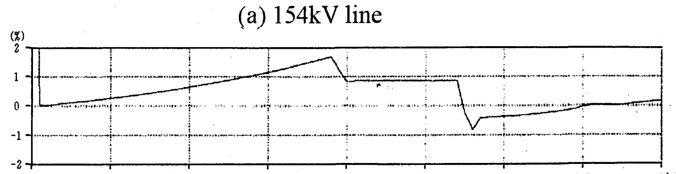
Fig.6: Impedance map of the ac side of the system.

CONCLUSIONS

The power supply system using SMES for the JHF 50-GeV main ring was proposed and the fundamental characteristics have been calculated. The proposed 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. The proposed system can be applicable for magnet power supplies of large scale accelerators.



(a) 154kV line



(b) 66kV line

Fig.7: Calculated line voltage fluctuation.

REFERENCES

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