APPLICATION OF ENERGY STORAGE SYSTEM FOR THE ACCELERATOR MAGNET POWER SUPPLY*

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Abstract

Magnets of the synchrotron accelerator which extracts the accelerated beams are excited by pulse operation power supply, and then the load fluctuation should be a severe problem. An energy storage system, such as SMES, fly-wheel generator so far, will be required for compensating the pulse electric power, and reducing the disturbances of the connected power line. The system is also expected to protect the instantaneous voltage drop and contributes to storage ring reliability. Present status of R & D and the features for the energy storage systems are discussed. The application of the energy storage systems to synchrotrons for the medical use is described.

INTRODUCTION

Accelerators have been developed historically to use mainly for nuclear and particle physics experiments, and their characteristics have been improved to provide higher beam energy and beam intensity, and extended to collider machines. In some applications, synchrotrons are operated with a pulse mode for extracting accelerated beam. In case of large synchrotrons such as the J-PARC 50-GeV main ring, the CERN-PS and the BNL-AGS, large electric power swing is generated and electric disturbances occur in connected power networks. In such case some electric power compensation devices have to be installed.

Power supplies for larger accelerators are usually connected to their own dedicated power stations in order to suppress disturbances to networks. However, some compensation is required for suppression of the load fluctuation due to large power swing caused by the facilities. Authors have been carrying out for the power compensation of the J-PARC 50-GeV MR [1].

On the other hand, small-scale and low-priced accelerator facilities have been widely equipped for condensed matter physics and medical use following development of the accelerator technologies. Many medical accelerator facilities have been constructed and planned in the world. More than 20 facilities are operated, under construction, and planned in Japan. These facilities are composed of synchrotrons with pulse operation or cyclotrons. In case of small-scale synchrotrons, electric power is supplied from general commercial lines and compensation devices are also desirable even though the power fluctuations are small.

ELECTRIC ENERGY STORAGE SYSTEM

There are several kinds of energy storage devices that can be used for compensation of electric power fluctuation: fly-wheel generator (FWG), superconducting magnetic energy storage (SMES), capacitor, battery, and etc. The results of applications of these systems and their characteristics are summarized in Table 1. Table 1 shows that FWG and/or SMES systems are appropriate for the power compensation of large apparatus which requires fast response. The FWG has been practically used since early times for power compensation for fusion devices and power networks [2-3].

Table 1: Electric Power Compensators and Their Applications

Apparatus	Characteristics	Results: Facility	Results: Capacity
FWG	Fast response	Keihin El. Express Railway	25 kWh
	Repetitive stress	Okinawa Electric Power	200 MJ
		Fusion: JT-60	1300 MJ
	Maintenance	(Accelerator: J-PARC)	51MVA
SMES	Fast response	Accelerator: BNL NSLS	2.4 MJ
	High efficiency	UPS: Sharp Kameyama Plant	10 MJ
	AC loss	El. Power: National project	20 MJ
		Kyushu Electric Power	3.6 MJ
		(Accelerator: J-PARC)	90MVA
Capacitor (EDLC)	Fast response	UPS: Sharp Kameyama Plant	200kVA
	Small & med. Size	(Accelerators: BNL-AGS, CERN-PS)	
		HEV truck	50 – 500 kW
	Repetitive life		*~100,000*
Battery	Small & med. size	HEV truck	50 – 500 kW
	Repetitive Life		*~1,000*
	Maintenance		

The parentheses indicate under investigation.
The italic words mean shortcomings.

However, in case of synchrotrons, power transfer is required for 10^7 to 10^8 times over their lifetime of usually 20 to 30 years, so it is important to take into consideration the number of repetition times. For example, the KEK-12 GeV proton synchrotron (KEK-PS) was operated for 5000 to 6000 hours per year for 30 years [4]. Depending on the physics experiment, pulse operation periods were 2 to 4 seconds, giving at least 1.4×10^8 cycles. In such a case FWG risks breakdown and therefore calls for preventive maintenance.

SMES has the merit of higher efficiency than other storage devices since it stores electric power directly.

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Moreover, it has the potential of long life since there are no mechanical moving components. SMES has been expected as an alternative measure to the hydro-pumped storage and the power network stabilizer, and was actively investigated for this purpose since 1970's [5]. First application of SMES was proposed and experimental studies were performed for the 12GeV-PS main ring power supply [6].

Following recent technological innovation for the fast control of converters using semiconductor devices, applications to stabilize voltage and frequency fluctuations of power networks and to compensate load fluctuations have been studied. A SMES system was developed for the UPS application in a liquid crystal display panel factory [7], [8], and the first system, with a capacity of 10 MJ, has already been installed [9].

A national project to develop SMES had been carried out for the application to voltage and frequency stabilizations and load compensation of power networks. By this project, a SMES test module had been constructed and successfully tested by connection to a practical power network with small hydroelectric power stations and a metal rolling factory [10]. The test showed that the SMES system is very effective for stabilizing voltage and frequency fluctuations of power networks.

Table 2 : Parameters of Electrical Power Equipment for Large Synchrotrons

	KEK-PS	J-PARC	CERN-PS	BNL-AGS
Repetition (s)	2.5-4.0	3.64	2.5	1.4 – 3.0
P_{total} (MW)	23.6	105	40	50/70
V_{prim} (kV)	154/66/ 6.6	66/22/6.6	130/18	138/69/ 13.6
Compensator	20 MVA SVC	51 MVA FW 90 MVA-SMES	7 MW-motor 90 MVA-FW (233 MJ) SVC or SMES	9 MJ MG (34 MJ MG) => 12.6 MJ capacitor
Comments	Shut down in 2006	Phase II	Injector for LHC	Injector for RHIC

SVC: Static Var Compensator

APPLICATION FOR THE LARGE SYNCHROTRONS

The parameters of compensation devices using SMES for large accelerators, such as the J-PARC 50-GeV MR [1] and the CERN-PS power supplies [11], are shown in Table 2. For use with accelerators, a battery is not appropriate because of its lifetime. However, the electric double layer capacitor (EDLC) with relatively large capacity has been developed for HEV trucks, and is attractive (even though still limited with respect to number of cycles). The use of EDLC has been studied for the AGS power supply at BNL [12] and the CERN-PS [13]. SMES is also a candidate for such applications. Original design of the J-PARC-50GeV-PS is used with FWG [14], then, small scale FWG experiment had performed in the early stage of this project[15] , which was supported by the Joint Development research at KEK. Figures 1 and 2 show the FWG and SMES application for J-PARC 50-GeV MR power supply, respectively.

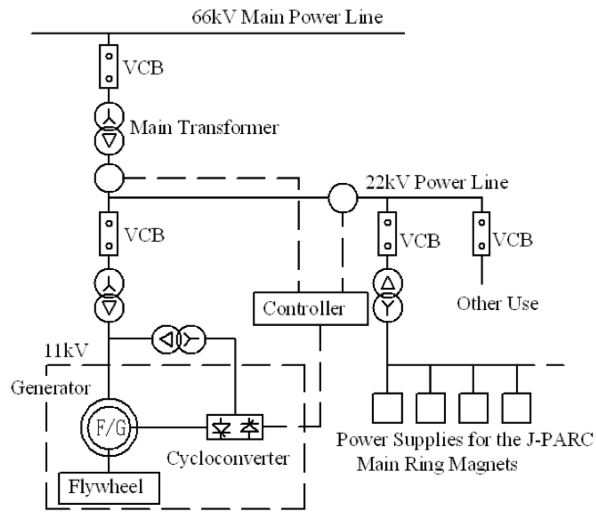

Fig. 1: Configuration of the FWG system for the J-PARC 50-GeV MR power supply

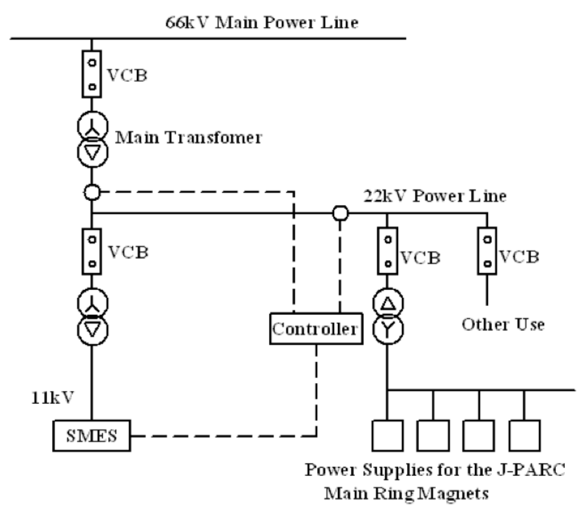

Fig. 2: Configuration of the SMES for the J-PARC 50-GeV MR power supply

APPLICATION FOR THE SMALL-SCALE SYNCHROTRONS

More than twenty medical facilities for cancer therapy using synchrotrons will be constructed in Japan, including eight facilities in operation and four under construction [16]. Five facilities are operated with proton beams and three with heavy ion beams. These synchrotrons require relatively low pulse power for their operation. However, their power supplies are usually connected not to their own dedicated high voltage substation but to conventional commercial lines. Therefore, it is necessary to install some power compensation devices to reduce disturbances so as not to affect sensitive and delicate instrumentation.

Moreover, it is expected that the operation cost will be reduced by the power compensation.

The peak power of a typical synchrotron power supply is 2-3 MW, and the cycle time is one to a few seconds in the example of the Hyogo Ion Beam Medical Center [17] and Gunma University Heavy Ion Medical Center [18]. If it is assumed that the operation time per day is 10 hours including preliminary tuning, the annual operation is 300 days and the life of machine is 30 years, then the total pulse repetition becomes about 10^8.

The study was performed on the cost performance of the SMES system to compensate load fluctuation of the synchrotrons for the medical use [19]. The small scale SMES has already been technically established and is sufficient for this application. Electric power can be saved by compensating input and output power by incorporating the SMES system.

At the end of this report, cyclotrons are also constructed for cancer therapy in foreign countries, and superconducting cyclotron development are under going in order to reduce the constructing and running cost [20].

SUMMARY

Authors strongly recommend that the application of SMES will be effective to compensate the electric power fluctuation and power saving since the recent technological innovation for the fast control of converters using semiconductor devices and an application to stabilize voltage and frequency fluctuations of power networks.

It is planned to construct a medical facility in every prefecture, that is, fifty facilities in Japan. From both the economic and environmental standpoints, it is important to plan to install the SMES system at the beginning of the planning of construction. Thus, nation-wide, there is the potential for saving annually electric power of 60 GWh.

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