§13. Study on Power Supply System for Superconducting Magnets Using Low Frequency Power Transmission

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Several sets of large superconducting magnets are used in magnetic confinement fusion devices. To excite these superconducting magnets, semiconductor rectifiers using current control, which has a commercial frequency input, is commonly employed. Some of the fusion experimental devices also use super-conducting cables to connect between magnets and power supplies. In this research, a low frequency ac (LFAC) system which converts power from a commercial frequency to a low frequency of around 10 Hz, sends it through superconducting cables, and converts it again to dc power near superconducting magnets is investigated. This LFAC system has an advantage over a commercial frequency ac system, which is reduction of ac losses in superconducting cables, and also advantages over a dc distribution system, which are easy power conversion using a transformer and easy fault protection. Figure 1 shows an example of a LFAC system to a fusion reactor. This research focuses on the power supply for the superconducting magnet shown as LFAC/DC in Fig. 1.

For this application, a low-voltage large-current power supply is required, and a thyristor converter is conventionally employed. However, it has drawbacks: it generates large reactive power especially in low voltage operation and a dc filter becomes large due to the low frequency input. To solve these problems, as a dual circuit of voltage-source type modular multilevel converter suitable for high voltage application due to a number of series-connected chopper cells, a current-source type modular multilevel converter (CSMMC) is newly proposed, which is easily applied to the large current power supply by connecting choppers with an inductor in parallel. The CSMMC can remove reactive power compensators and downsize the dc filter because it operates at unity power factor and at high switching frequency. The circuit configuration of CSMMC, arms of which have two parallel-connected choppers, is shown in Fig. 2.

Simulation of the CSMMC charging and discharging a superconducting magnet was carried out using an ideal power source with a frequency of 10 Hz. Major parameters are summarized in Table I. The reference of magnet current i_{sc}^* had an increase rate of 1200 A/s related to a rating output voltage of 45 V, and a maximum value of 6 kA. Simulation results in Figs. 3 and 4 shows desired performances: the ripple of magnet voltage v_{sc} was less than 0.4%, the control error of magnet current i_{sc} was around 0.2% at steady state, and displacement power factor was kept at almost unity. Moreover, compared with the dc filter of the low-frequency thyristor rectifier, whose inductance and capacitance are 117 μF and 2.16 F, respectively, the CSMMC eliminates the inductance and decreases the capacitance to 300 mF. These results indicate that the CSMMC is suitable for the power supply of superconducting magnets of the fusion reactor.

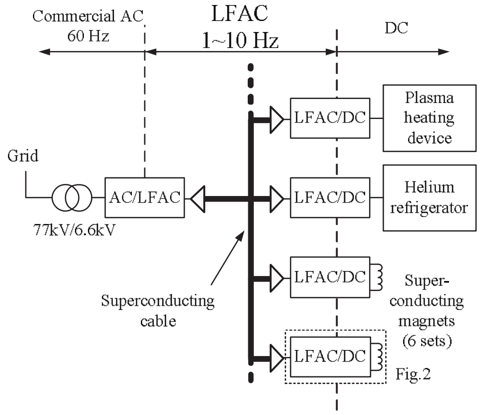

Fig. 1 An LFAC system applied to a fusion reactor.

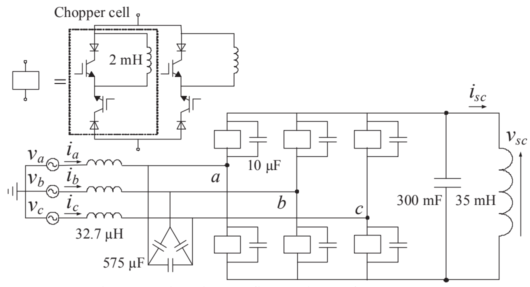

Fig.2 Circuit configuration of CSMMC.

Table I Major parameters of the CSMMC

Rated active power	270 kW
Rated dc voltage	45 V
Rated dc current	6 kA
Sampling frequency	4 kHz
Inductor current	3 kA

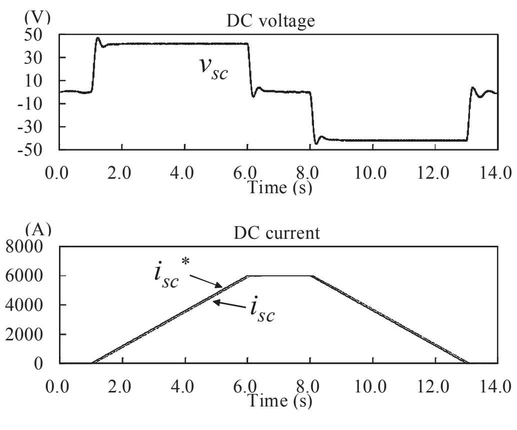

Fig. 3 Simulation results of the CSMMC charging / discharging a magnet.

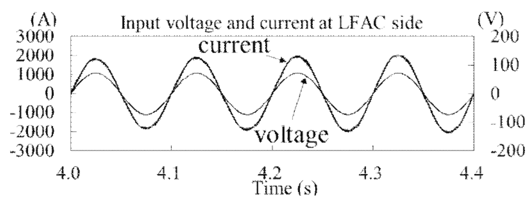

Fig. 4 Input voltage and current waveforms at LFAC side.