§8. Power Supply System for Nuclear Fusion Plant Using DC Power Distribution

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Recent years, application of dc power distribution system is vigorously investigated for factories, households, and microgrids as well as ICT data centers. The dc power distribution can make power plant system efficient, simple and compact because it can connect dc input/output devices directly and reduce the number of power conversion such as ac/dc and dc/ac conversion. In a magnetic confinement type nuclear fusion device, since many dc power components such as magnetic field coils exist, application of dc power distribution is effective. Moreover, applying of a superconducting cable can realize higher efficiency and downsizing of the system. In this research, application of dc power distribution system using superconducting cables to the nuclear fusion device is investigated.

A nuclear fusion plant has various loads such as superconducting coils, plasma heating devices, etc., and their required voltage levels are very different. Hence, in our proposed dc power distribution system, power is provided by two dc buses which have different voltage of 3 kV and 400 V, respectively, and supplied to loads through dc/dc converters which condition voltage properly. The conceptual configuration of the system is shown in Fig. 1. Each power supply isolates a load from buses by a high frequency transformer. A superconducting coil power supply consists of two converters: one is a bidirectional converter for excitation and de-excitation of the coil, which can output several hundred volts. The other is a low-loss unidirectional converter for steady state operation, which supplies a few volts. Both the converters receive power from 400-V bus. On the other hand, a NBI heating device power supply receives power from both of 3-kV and 400-V buses because the NBI heating device has an acceleration electrode and an ion generator which require very high and low voltage, respectively. In addition, power supplies for large capacity loads such as a helium refrigerator are connected to the high voltage bus.

In the case that the dc power supply system employs superconducting cables and has constant power loads, the system can be unstable. We conducted theoretical and simulation analysis of stability for the system, which consists a rectifier that connects an ac grid and dc bus, a dc/dc converter that supplies power to a constant-power load, and superconducting cables. As a result, we made clear unstable operational area of the system within the range of cable length of 1000 m and supplied power of 1 MW, and also confirmed stable operational area was increased drastically by applying of resonance suppression control to the rectifier and dc/dc converter.

Next generation SiC devices have higher switching speed and lower loss characteristics than presently mainstream Si devices, and therefore can realize high efficiency and downsizing of power supplies. We made a boost chopper by employing two types of SiC JFET and a SiC Schottkey barrier diode, shown in Fig. 2. Measured efficiency is shown in Fig. 3. For both the type of JFETs, efficiency was higher than 96% in the range of switching frequency lower than 500 kHz. These results suggest application of SiC devices has the possibility of realization of a small-size and high-efficiency power converter with a high operational frequency in the dc power distribution system.

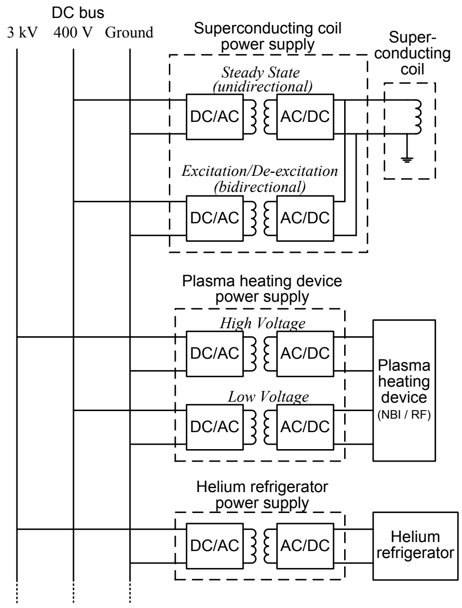

Fig. 1 Conceptual configuration of dc power distribution system for nuclear fusion plant.

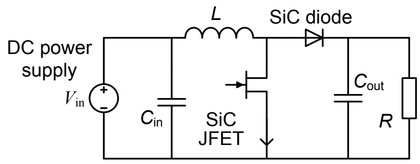

Fig. 2 Circuit configuration of the boost chopper.

Table I Major parameters of the boost chopper.

SiC JFET type A	1200 V / 5A, R_{on} = 0.42 Ω, SiCED
SiC JFET type B	1200 V / 5A, R_{on} = 0.33 Ω, SiCED
SiC Diode	600 V / 6 A, Infineon, SDP06S60
Input inductor, L	0.993 mH
Input capacitor, C_{in}	1500 μF
Output capacitor, C_{out}	2350 μF
Load resistor, R	99.5 Ω

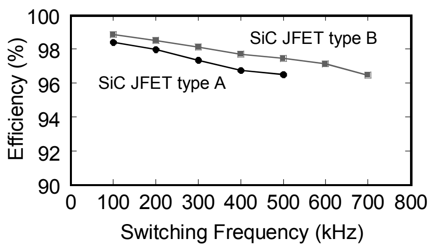

Fig. 3 Relationship between switching frequency and efficiency of the boost chopper (Input voltage, V_{in}: 155 V, output power, P_{out}: 500 W)