§11. Study on Current Source Type Modular Multilevel Converter for Large Superconducting Coil

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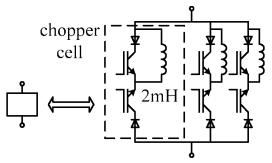
In this research, a low frequency ac (LFAC) system that distributes electrical power with a low frequency of around 10 Hz through superconducting (SC) cables, which is converted from a commercial frequency, and converts it again to dc power near SC coils has been proposed. This system has an advantage over a commercial frequency ac system, which is reduction of ac losses in SC cables, and also advantages over dc distribution system, which are easy power conversion using transformers and easy fault protection.

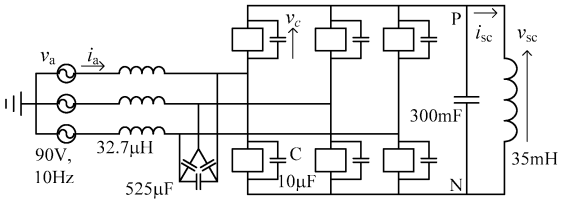
In the LFAC system, low voltage large current power supplies are required, and a thyristor converter is conventionally employed for this application. However, it generates large reactive power especially in low voltage operation and needs a large dc filter due to the low frequency input. To solve these problems, we have newly proposed a current source type modular multilevel converter (CSMMC), which is easily applied to the large current power supply by increasing the number of parallelly-connected choppers with an inductor as shown in Fig. 1, and it is a dual circuit of voltage source type modular multilevel converter widely-used for high voltage applications. The CSMMC can eliminate reactive power compensators and downsize the dc filter because it operates at unity power factor and at a high switching frequency. .

In the previous work, numerical simulation of the CSMMC with two chopper cells on each arm was conducted, and sufficient control performance of SC coil current on a dc side and operation at unity power factor with low harmonic distortion on an ac side was confirmed. However, simulation results indicate that high voltage of approximately 600 V is generated at the moments of current commutation across the buffer capacitor C that is connected in parallel to each arm. This high voltage results that a voltage rating of semiconductor devices becomes higher and consequently power losses in the converter increase. As the result of investigation of this year, it was found that high voltage is generated by flowing of the current into the buffer capacitor, which is caused by difference of currents between positive (P) side conducting cells and negative (N) side conducting cells at current commutation. To suppress the voltage, a switching scheme of semiconductor devices was studied and modified. Moreover, the number of parallelly-connected choppers in one arm was increased from two to three in order to reduce the difference of current between P side cells and N side cells.

Simulation of the CSMMC with three parallelly-connected choppers applied to the LFAC system with ac source voltage and frequency of 90 V and 10 Hz, respectively, was carried out. Major parameters are summarized in Table I and Fig.1. The reference of magnet current i_{sc}^* was given with 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 Fig. 2 shows that desired performances on both the ac and dc sides were achieved. The buffer capacitor voltage was sufficiently suppressed to less than 300 V and it indicates that semiconductor devices with a low voltage rating and low power losses can be employed to the proposed circuit. However, the buffer capacitor voltage is still relatively high compared to the ac input voltage of 90 V. Therefore further investigation on suppression of the voltage is required.



(a) Parallelly-connected chopper cells (arm part in (b)).

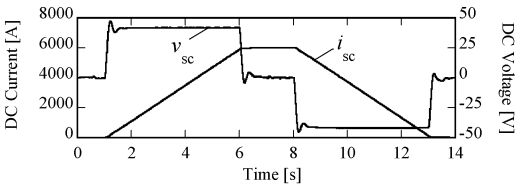


(b) Circuit configuration.

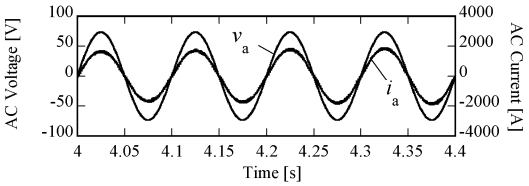
Fig. 1 Current source type modular multilevel converter.

Table I Simulation condition

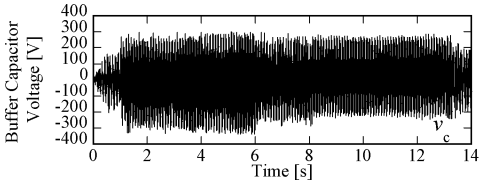
Rated active power	270 kW
Rated dc voltage	45 V
Rated dc current	6 kA
Sampling frequency	4 kHz
Chopper Cell inductor current	2 kA / cell
AC Voltage	90 V_{rms}
AC frequency	10 Hz



(a) Current i_{sc} and voltage v_{sc} of SC coil.



(b) Phase voltage v_a and current i_a at LFAC side.



(c) Buffer capacitor voltage v_c.

Fig. 2 Simulation result of charge / discharge of SC coil.