DEVELOPMENT ON ADVANCED CURRENT-SOURCE-TYPE SELF-COMMUTATED CONVERTER FOR ACCELERATOR ELECTROMAGNETS

Eiichi Ikawa, Toshiba Corporation, Japan
Koji Noda, NIRS, Japan

Abstract

A new power supply system for accelerator electromagnets is proposed based on the advanced current-source-type self-commutated converter (ACSC).

The ACSC offers simple AC to DC conversion system resulting in economical and reliable power supply for the accelerator. Furthermore, the ACSC operates in unity power factor and with little harmonics to the AC network.

An ACSC mini-model using IGBT was made and evaluated at the maximum output current of 1600A .The experimental results showed the current ripple less than 1×10^{-6} and the tracking error less than $\pm0.5\times10^{-4}$.

1 INTORODUCTION

The ACSC system has a capacitor in the bridge arm, which softens the turn-off phenomena, while the conventional current-source-type converter (CSC) places large filter capacitors at the AC input. Thus, the conventional CSC sometimes yields resonance between AC network and the converter although the ACSC inherently does not [1][2].

As one of the applications, the ACSC is considered suitable to the accelerators, which are used in the field of HIMAC (at NIRS, Japan). The power supply is required to suppress ripples including ringing less than 10^{-6} at the flat top of the current pattern in the DC circuit. It is also required precisely to follow the trapezoidal current pattern at the same time. The ACSC can flexibly control its DC voltage output by its self-commutation ability. Thus, the ACSC is expected to achieve such requirements for high quality. In addition to the performance, the ACSC is expected to offer better cost-performance for such application since the system consists of the converter and a special filter with variable impedance [3].

In this paper, the ACSC is explained from the aspects of the configuration, the principle of operation and the advantages. The ACSC performance is evaluated by the experimental results from ACSC mini-model tests.

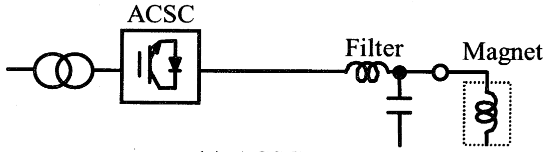
2 SELF-COMMUTATED CONVERTERS

2.1 Configuration of the self-commutated converters

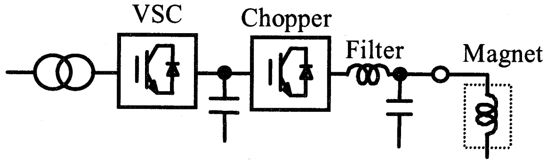
The self-commutated converters are constructed with self-commutated switching device such as IGBT for low voltage, IEGT (Insulated Gate Enhanced Gate bipolar Transistor) for high voltage. By controlling the switching device as intended, the self-commutated converter offers advantages as follows.

- Fast control response
  (1) Fast response to the DC current pattern
  (2) Immunity to AC network disturbance
  (voltage variation, flicker and so on)
- Small disturbances to AC network
  (1) Unity power factor
  (2) Suppressing harmonics current

Two types of converter system can be applied for accelerator electromagnets. One is the ACSC system and the other is the voltage-source-type converter (VSC) with the chopper system as shown in Figure 1 (a), (b), respectively. The ACSC system configuration is simple since it converts AC power to DC power directly.



(a) ACSC system



(b) VSC with chopper system
Figure 1 Power supply systems

2.2 Operation principle of the ACSC

The feature of the ACSC is the arm capacitor as shown in Figure 2. The operation of the ACSC consists of four modes as shown in Figure 3.

(1) On-state: The switch devices S1 and S2 conduct parallel through the diode D1 and D2, respectively.
(2) Turn-off: The arm capacitor Cs is charged by the current flowing through D1and D2.
(3) Off-state: The bridge arms are all in off-state.
(4) Turn-on:The charges in Cs is discharged through S1 and S2 and regenerated to the AC input.

Since the capacitor is separated from the AC input by switches, the capacitor capacity can be easily increased and the AC capacitor can be eliminated. Thus the ACSC has the advantages compared with the conventional CSC as follows.

- No resonance between AC network and the converter due to no AC capacitor
- Small switching loss by suppressing di/dt and dv/dt with the arm capacitor

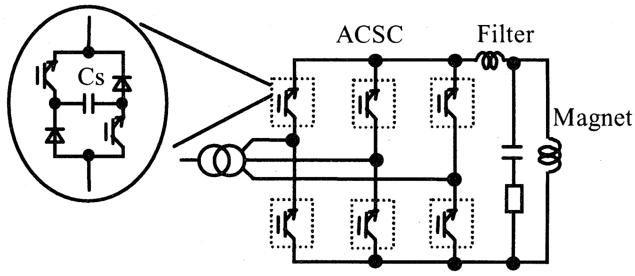


Figure 2 ACSC configuration

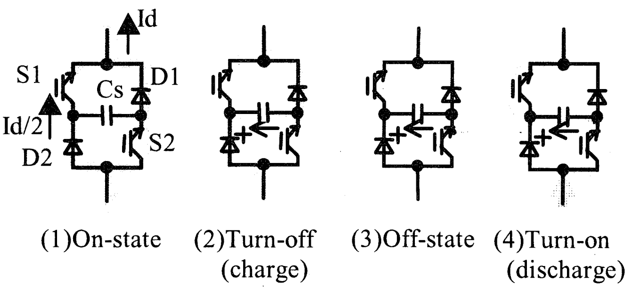


Figure 3 Operation principle of the ACSC

3 ADVANTAGES OF ACSC

The ACSC system has two advantages. One is the number of devices and the second is the protection. The ACSC consists of only the converter while the VSC requires chopper to convert the DC voltage to the DC current in addition to the converter as shown in Figure 1 (b). Thus, the ACSC can be manufactured with smaller number of devices than the VSC with the chopper. The smaller number will result in smaller loss and better cost-performance. Since the ACSC is the current-source-type converter, the established protection system used in the thyristor converter can also be applied.

The features and performances of the power supply systems are summarised in Table1.

Table 1: Comparison of ACSC and VSC with chopper

System	ACSC	VSC with chopper
Configuration	Converter	Converter +chopper
Device Number	Rather small	Rather large
Control response	Good	Good
Power factor	Unity	Unity
Dimensions, Loss & Costs	Rather small	Rather large
Protection	Simple (conventional)	Need for high-response fuse

4 ACSC MINI-MODEL EVALUATION

4.1 Mini-model

In order to evaluate the ACSC system, a mini-model was made as shown in Figure 4, with a variable impedance filter introduced in another paper. The parameters of mini-model are listed in Table 2.

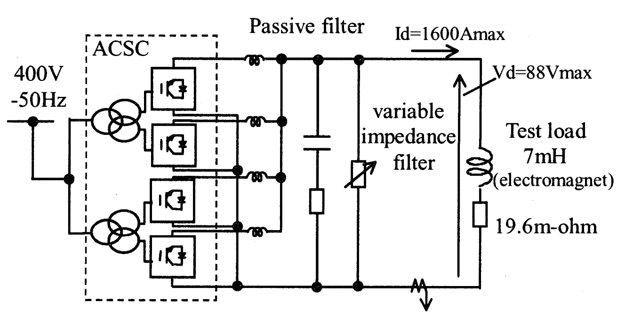


Figure 4 ACSC mini-model

Table 2 Parameters of ACSC mini-model

Ratings	141kVA-88V-1600A
Device	IGBT
Configuration	Four bridges in parallel
Switching frequency	450Hz (9pulse PWM)

The control is implemented in full digital controller driven by the 32-bit CPU and DSP. The PWM control is adapted for the converter as shown in Figure 5.

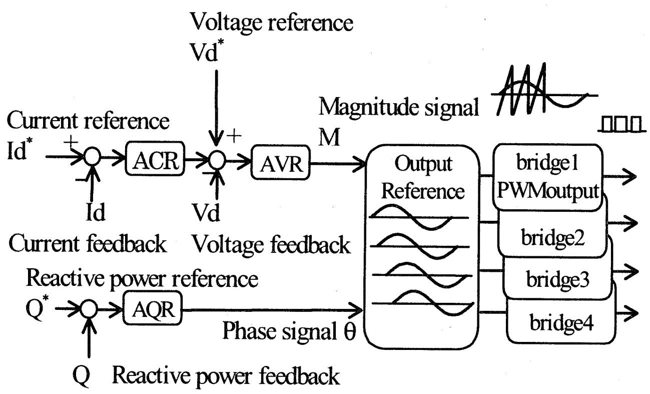


Figure 5 Control method

4.2 *Experimental results*

The experimental results from the ACSC mini-model tests are shown in Figures from 6 to 8.

Figure 6 shows the current ripple waveforms at DC operation with the maximum output current of 1600A.

Figure 7 shows the FFT analysis of the DC voltage. The current ripple was calculated with the load impedance and the DC voltage spectrum.

The calculation results of the ripple current are listed in Table 3. For HIMAC Bending Magnet (BM) system, the ripple should be less than 10^{-6}. The ripple is estimated by Equation (1), considering the voltage and current ratings and the load impedance of the mini-model and HIMAC BM. From Table 3, the precision requirement is proved to be achieved.

$$Id\_ripple=Vd\_max*dt/(R+sL)/Id\_max \qquad (1)$$

where, R:load resistance, L:load inductance, dt: ripple frequency period

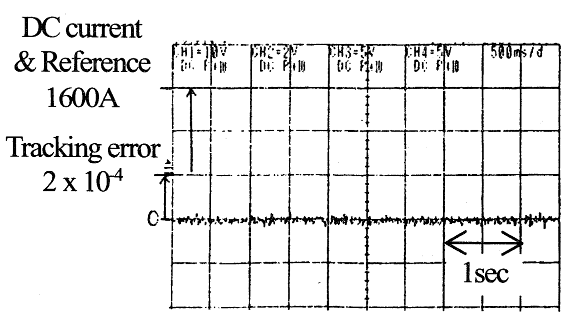


Figure 6 Current ripple waveforms

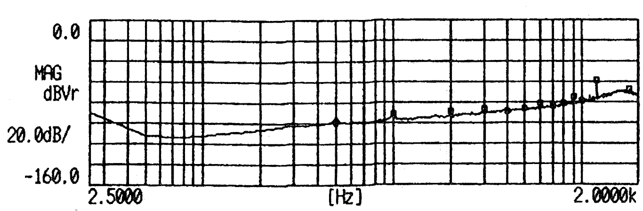


Figure 7 DC voltage spectrum

Table 3 Current ripple at DC1600A

F(Hz)	DC Voltage Ripple (dBVr)	DC Current Ripple(p-p) *calculation for 7mH	DC Current Ripple(p-p) *expect for HIMAC
50	-98.17	4.962E-6	9.469E-7
100	-91.68	5.237E-6	9.995E-7
200	-88.28	3.873E-6	7.392E-7
300	-86.71	3.094E-6	5.904E-7
400	-88.43	1.904E-6	3.633E-7
500	-86.65	1.869E-6	3.567E-7

Note: DC voltage probe 500:1

Figure 8 shows the tracking error, the error between the Reference current and the DC current, which is normalized by the maximum DC current. At a trapezoidal current pattern (flatbase:7%, flattop:100%, rising time:1s), the tracking error was within $0.5*10^{-4}$. From the experimental results, the response requirement is also proved to be achieved.

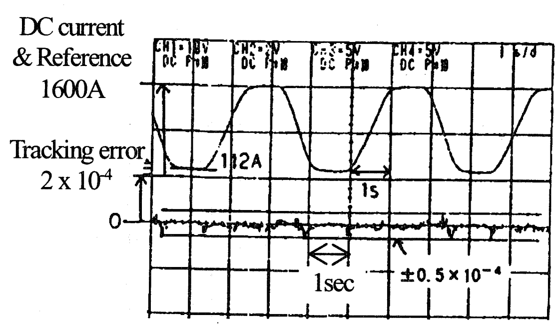


Figure 8 Tracking performance

4 CONCULUSION

A new power supply system is proposed and developed for accelerator electromagnets. The system is based on the ACSC. The ACSC system has the advantage of configuration, dimensions, and reliability. The ACSC mini-model using IGBT was made and the experimental results showed successful performances.

REFERENCES

[1] Takami Sakai et al, "SMES system with snubber loss free type current source converter", IECON'97, Louisiana, Nov. 1997

[2] Takami Sakai et al, "Consideration on Self-Commutated Converter Characteristics for DC Power Supply ", IPEMC'2000, Beijing, Aug. 2000

[3] Teruo Yoshino et al, "Development on Hybrid Filter for High-Precision Power Source to Accelerator Electromagnets",SAST'01,Osaka,Oct.2000