J Electr Eng Technol Vol. 8, No. 2: 326-330, 2013
http://dx.doi.org/10.5370/JEET.2013.8.2.326

ISSN(Print) 1975-0102
ISSN(Online) 2093-7423

Superconducting Magnet Power Supply System for the KSTAR 2nd Plasma Experiment and Operation

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Abstract – The Korea Superconducting Tokamak Advanced Research (KSTAR) device is an advanced superconducting tokamak to establish scientific and technological bases for attractive fusion reactor. This device requires 3.5 Tesla of toroidal field (TF) for plasma confinement, and requires a strong poloidal flux swing to generate an inductive voltage to produce and sustain the tokamak plasma. KSTAR was originally designed to have 16 serially connected TF magnets for which the nominal current rating is 35.2 kA. KSTAR also has 7 pairs of poloidal field (PF) coils that are driven to 1 MA/sec for generation of the tokamak plasma according to the operation scenarios. The KSTAR Magnet Power Supply (MPS) was dedicated to the superconducting (SC) coil commissioning and 2nd plasma experiment as a part of the system commissioning. This paper will describe key features of KSTAR MPS for the 2nd plasma experiment, and will also report the engineering and commissioning results of the magnet power supplies.

Keywords: KSTAR, Converter, MPS, TF, PF, QP, Blip resister insertion system (BRIS)

1. Introduction

The Korea Superconducting Tokamak Advanced Research (KSTAR) [1] project has completed its construction of the TF and PF magnet power supply (MPS) system in its configuration and launched the self commission at May 2008. This work describes the configuration of the Toroidal Field (TF) and Poloidal Field (PF) Magnet Power Supply (MPS) systems, and summarizes the test result of the system at room temperature, which was successfully completed for the preparation of a real system test with the SC coil load after cool-down at 2009.

2. TF MPS System

The TF MPS that consists of 16 paralleled IGBT-based full-bridge inverter type module was designed to have features of low voltage and high current through improvement on the ac input waveform, and through the reduction of output voltage and current ripple. Miniaturization by choosing diode rectifier in module concept can be realized by high frequency based operation and high power factor. Another unique feature of the module is easy maintenance and repair with help of the module concept. A circuit diagram of the module is shown in Fig. 1, and detailed specifications of the converter module are as follows:

Input voltage; AC 380 V
Output voltage; DC 0~50 V programmable
Output current; DC 0~3 kA programmable
Carrier frequency; 16 kHz

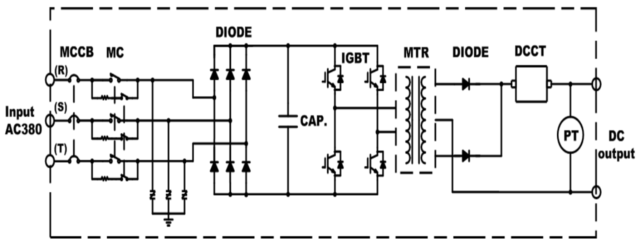

Fig. 1. Circuit diagram of the converter module

The main components of the TF MPS system are composed of a converter for DC current output, a quench protector (QP) for slow and fast discharge current from the TF coil, a slow and fast discharge resistor (SDR/QPR) for energy dump by freewheeling current to a resistive path in case of SDC or QP triggering. This system also contains a quench protector (QP) for fast current discharge from the TF coils with a 7 s time constant in the event of a quench on the coil system. Another important component of the TF MPS is a slow discharge for normal current discharge from

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Received: November 12, 2010; Accepted: September 21, 2012

the coils with a 360 s of discharge time constant in the event of a start on the control system. A direct current disconnection switch (DCDS) that is the connecting switch between the TF coils and MPS system is one of the major component of the TF MPS system. The modules and DC bus-bars were actively cooled with de-ionized (DI) water for electrical insulation. The detailed specifications of the TF MPS systems are summarized in Table 1, and a schematic diagram of the system is shown in Fig. 2.

Table 1. Specifications of TF MPS system

Item	Specifications	Remarks
Input Voltage	380 V	
Output Voltage	0 ~ 50 V	Programmable
Output Current	36 kA	Max. 40 kA
Max. di/dt	60 A/s	
QP & QPR	40 kA	114 mΩ (Air cooling)
SDC & SDR	40 kA	2.2 mΩ (Air cooling)
DCDS	36 kA	Max 40 kA
DC Busbar	36 kA, (water cooling)	160 ℓ/m (DI water)
Fast discharge time	7 sec	time constant
Slow discharge time	360 sec	time constant

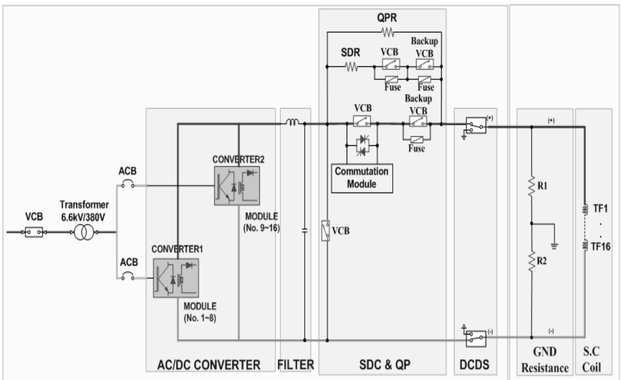

Fig. 2. Schematic diagram of the TF MPS system

The TF MPS system should operate in steady state for more than 8 hours during the plasma experiment. Therefore, this system requires a highly qualified safety aspect during the plasma operation. For a local system commissioning of the TF MPS system before machine cool-down, the TF MPS system was tested at room temperature by connecting the two current output terminals due to the unavailability of the SC TF coils in this period.

2.1 Result of local system commissioning

The local system commissioning covered several critical tests such as a current charging up to 36 kA, quench protection test, slow discharge circuit test, interlock, and local & remote control performances. Fig. 3 shows the temperature of the TF MPS component during the operation with 36 kA of current charging. The test result was proven to be quite satisfactory in spite of a few trivial problems that were solved in a day.

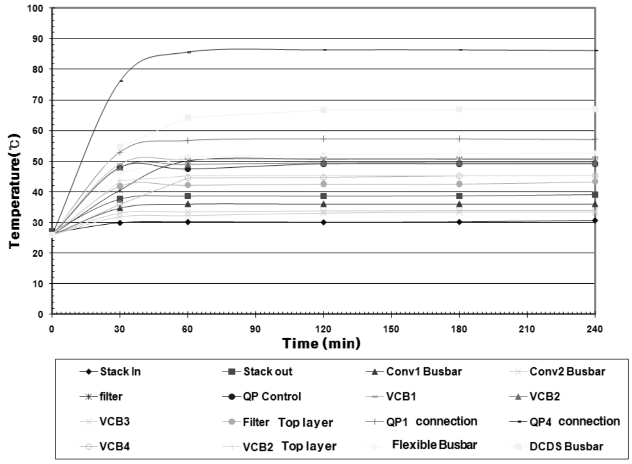

Fig. 3. Temperature of the TF MPS components @ 36kA

2.2 Operation result of the SC coil load

As a final step in the system commissioning for both the TF MPS and the TF coil, a current charging experiment to 36 kA for 8 hours was successfully implemented during the SC coil commissioning stage. Fig. 4 shows the output current waveform during the final power supply test of which the maximum output current was 36 kA. In the test, the output voltage continuously increased as the operation time, which is believed to be stemmed from increase of the resistance in the normal bus-bars between the MPS and superconducting (SC) coils.

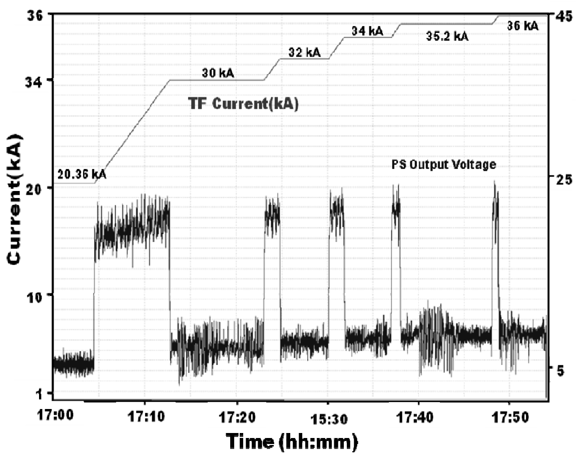

Fig. 4. Output current data of the TF MPS

3. PF MPS System

The PF MPS consists of 7 independent supplies to supply current to the 7 pairs of PF SC coils up to 20 or 25 kA. Consequently, the output voltage of each PF MPS shows various values from several hundred V to 1 kV according to the load characteristics and operation regime. Each PF MPS is composed of a converter unit that uses bi-directional and 12-phase thyristors, a QP for fast current discharge from the PF coils with a 4 s time constant in the event of a PF coil quench, a Blip Resistor Insertion System (BRIS) for producing a flux swing from a rapid change in the current, a Direct Current Disconnection Switch (DCDS) that acts as a main connecting switch between the PF coil and PF MPS system, and a DC bus-bar. The detailed specifications of the PF MPS system are summarized in table 2 and a schematic diagram of the system is shown in Fig. 5.

Table 2. Specifications of PF MPS system

MPS	Specifications							
	Converter	Converter AC input voltage	DCL	BRIS	Blip R [Ω]	QP	QPR [mΩ]	DC Busbar
PF1	1kV/25kA	320 V	0.4 mH	3kV/**3.4kA**	0.4, **0.5**, 0.6	2kV/25kA	41	8kA/300sec
PF2	1kV/25kA	320 V	0.4 mH	3kV/**3.4kA**	0.4, **0.5**, 0.6	2kV/25kA	31	8kA/300sec
PF3L	500V/25kA	160 V	0.4 mH	3kV/**3.4kA**	**0.5**, 0.7, 0.9	2kV/25kA	7	8kA/300sec
PF4L	500V/25kA	160 V	0.4 mH	3kV/**3.4kA**	0.5, **0.7**, 0.9	2kV/25kA	9.5	8kA/300sec
PF5L	1kV/25kA	1,100 V	0.4 mH	5kV/**2.1kA**	1.6, 1.9, **2.2**	2kV/25kA	41	8kA/300sec
PF6L	1kV/20kA	1,100 V	0.4 mH	5kV/**2.2kA**	1.8, **2.1**, 2.2	3kV/20kA	82	8kA/300sec
PF7	1kV/20kA	1,100 V	0.4 mH	-	-	3kV/20kA	101	8kA/300sec

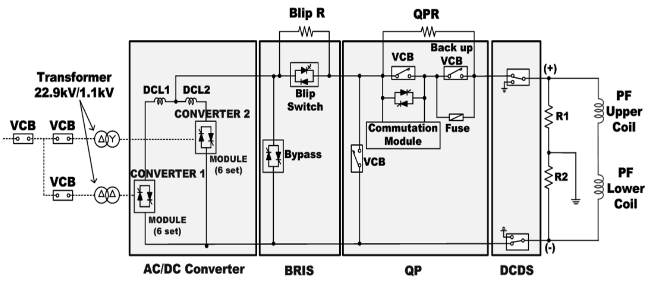

Fig. 5. Schematic diagram of the PF MPS system

Although the converter unit for each PF MPS has current rating of 20 kA (or 25 kA), and the converter has capacity of bi-directional operation, the PF MPS could not be equipped with BRIS except for the PF 7 MPS for the 1st plasma experiment. However, a bi-directional operation scenario for the 2nd plasma experiment could be realized after installation of QP system for every PF MPS system. In addition to the absence of the QP system, another constriction of the system was the current rating of the BRIS for each PF MPS that has about 3 kA of maximum current level. The two major limits described above resulted in the maximum available current was ±4 kA, and maximum total flux was less than 1 Webber (volt-second) in the 2nd plasma experiment. The limited available total flux was a major constriction for the pulse length of the 2nd plasma experiment, which was set at about 3 sec.

3.1 Result of local system commissioning

A system test of the 7 sets of PF MPS system with a dummy coil was carried out by measurements of output current. The current charging tests were followed by dummy loads that had self inductances of 40 mH. Fig. 6 shows the dummy load of which self inductance 40 mH. The tests included forward-direction current charging, reversed-direction current charging, and zero-crossing tests. Fig. 7 shows the result of zero-crossing test. The zero-crossing tests showed a dead time about 10 msec. The PF QP, BRIS, interlock system, and remote control system were also finally tested after the current charging tests. In this period, every major and minor problem was successfully solved and all of the PF MPS were ready for final commissioning with real SC coil loads.

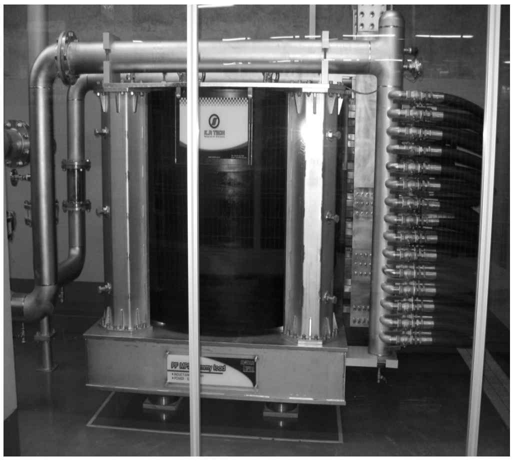

Fig. 6. Dummy load with PF MPS system test

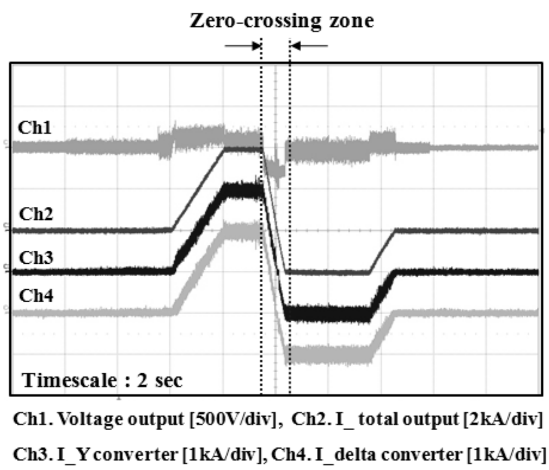

Fig. 7. Result of current charging and zero-corssing operation

3.2 Operation result of the SC coil load

The final system commissioning of the PF MPS with superconducting loads was performed with PF SC coils in the middle of October 2009. Gains of all the PF MPS were carefully tuned for optimum conditions for the current ripple with low output current. The operational reliability was also checked for the PF QP, PF BRIS, interlock, and remote control systems. In this commissioning, the maximum current applied to the PF coils was ±4 kA in the bi-direction and zero-crossing operation. The QP operated well when an artificial quench signal was generated and sent to the QP system. The current waveforms with the BRIS operation also satisfied the requirement for the 2nd plasma generation. Fig. 8 shows the current waveforms applied to the 7 sets of PF coils. The maximum output current of all PF MPS was ±4 kA, the current ramping rate was maintained at 1 kA/sec, and the experimental data of Fig. 8 shows the operation result of the blip and plasma control during the KSTAR 2nd plasma experiment.

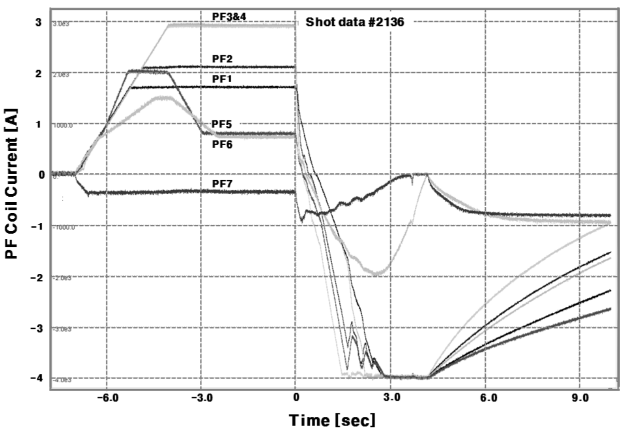

Fig. 8. Result of PF MPS operation

4. Conclusion

The TF and PF MPS systems satisfactorily operated in the integrated commissioning phase and in the 2nd plasma experiment period with no severe problem preventing machine operation. A successful result in the magnet power supply commissioning and operation was one of the most important factors for the success of the KSTAR 2nd plasma experiment. However, every power supply system in the 2nd plasma experiment had a configuration restricted from its full specification. This fact was a major limit for the 2nd plasma experiment, which achieved 320 kA of plasma current and duration of 3.6 s for a current of over 300 kA. It is most urgent for the power supply to be upgraded for future KSTAR operations. Therefore, The maximum capacity of the BRIS of the PF MPS system be upgraded from 3 kA to 25 kA and PF3U ~ PF6U converter until 2010.

The stability of the PF MPS system will be confirmed finally through the step-by-step performance test for the required maximum power under the superconducting magnet coil load until 2012.

Acknowledgements

This work is supported by the Korean Ministry of Education, Science, and Technology

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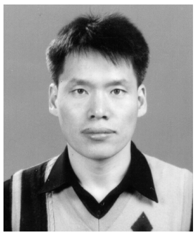

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