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Progress of procurement on the ITER NB ultra-high voltage power supplies
ITER中性粒子入射装置用超高圧電源調達の進展

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High-energy neutral beam injector is under development for heating and current drive of ITER plasma in collaboration with EUDA. JAEA(JADA) will provide ultra-high voltage DC power supplies which can generate -1 MV DC power for the negative ion beam source. Present status of the design on the power supply is reported as a contribution by JADA for the ITER Neutral Beam Injector. R&D status regarding the ceramic insulation tubes for water choke and the DC -1 MV insulating transformer is also reported.

1. Introduction

Two high-energy neutral beam injectors (NBI) with the beam energy of 1 MeV and the neutral beam injection power of 16.5 MW/injector will be installed in ITER for plasma heating and current drive [1]. Before the NBI operation in ITER, the Neutral Beam Test Facility (NBTF), which is almost the same system as the ITER NBI, will be constructed at the RFX site in Padua of Italy to confirm their specifications and to establish its operation techniques. For their NBI system, JAEA as Japan Domestic Agency (JADA) will provide ultra-high voltage DC power supplies for NBTF and ITER in collaboration with EUDA. Capacity of the power supply is supply DC -1 MV and 60 MW for the beam source with pulse duration up to 3600 s[2]. To construct such UHV NBI power supply, design study and R&Ds have been conducted and it is preparation for the procurement arrangement is in progress.

2. Requirements for ITER NB power supply

Issues for the power supply system are shown in Table 1. Electric breakdowns often occur in the accelerator and they make short circuit. Stored energy also flows into the accelerator from the stray capacitances existing between the high voltage parts and ground potential. Such energy input produces electrical damage for the accelerator. To accelerate the beam stably, prompt cut-off the high voltage power is required. Further suppression of energy input to the accelerator is essential to avoid the accelerator voltage holding degradation. To meet these requirements, a high frequency inverter system and high performance core snubber have been developed based on the technology for the high voltage power supply of the JT-60 N-NBI system in JAEA [3]. The same type of power supply has been proposed for the ITER NBI system.

In the R&D work, a ceramic insulation tube have been developed for the water choke to provide cooling water (<65 °C) for the ion source and accelerator electrodes with insulation of -1MV. Recently, DC -1MV insulating transformer development has started as ITER R&D task. DC -1 MV insulation is a key issue for the transformer.

Table 1 Status of the AGPS design for NB power supply

Items	Design Status
1) High speed switching of -1 MV output	Adoption of 150 Hz inverter system, which is based on the high voltage power supply of JT-60 N-NBI system [3].
2) Suppression of surge current	Installation of resistances and high performance core snubbers using Fe-based soft magnetic alloys (FINEMET), which was developed for high energy NBI power supply [4].
3) -1 MV transmission line	-1 MV insulation by SF_6 gas at 0.6 MPa. Basic performance of insulation has been tested.
4) -1 MV water choke	Ceramic insulation tubes with SUS flanges for high pressure and high water temperature cooling line have been developed [5]
5) -1 MV insulating transformer with 1 MV bushing	R&D started to demonstrate the DC -1 MV insulation for transformer and its bushing .

3. Status of design and development

3.1 -1 MV DC power supply

The ultra-high voltage DC power supply called AGPS (Acceleration Grid Power Supply) is inverter controlled power supply. A high frequency inverter system (6.5kV, 150Hz) controls the high speed switching of the DC -1MV without DC switches.

The inverter controls the voltage regulation too. Five 200 kV DC generators (Fig. 1) are connected in series at the DC output.

3.2 Water choke

The ion source is installed at – 1 MV, so the cooling water for the ion source needs to be insulated by the water choke system. A temperature of the cooling water is as high as 65 °C in ITER. Leak current will increase as temperature. It is not well known the insulting performance at high leak current. Therefore, R&D on the water choke to test insulation with a high leak current.

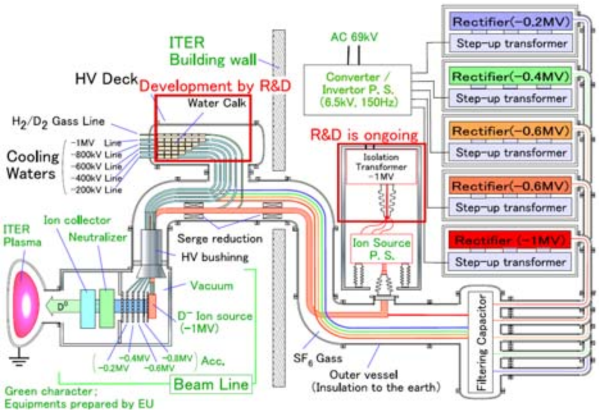

Fig. 1 Electric circuit diagram of the ITER NB system

For the insulation of such a high voltage, a compact insulation tube, which consists of a ceramic insulation tube (100 mm dia.) and two metal flanges, was developed to satisfy the requirements of high water pressure (2 MPa), high flow rate (>100 l/m) and high water temperature (<65 °C) for the ITER NB water choke [5]. The insulation performance of the developed tube was confirmed through high-voltage holding tests (110kV/tube 120 % of the rated voltage). The obtained results are summarized below.

1) Under the water flow condition, the voltage holding performance of a single ceramic tube was confirmed up to the test voltages of -129 kV. The voltage holding performance of two ceramic tubes connected in series was also confirmed so that the voltage can be increased linearly with number of the tube.
2) High voltage up to 110 kV was stably sustained for the following conditions.
   (1) Water temperature: 16 - 40 °C
   (2) Water flow rate: 50 – 140 L/min
   (3) Gas bubble mixing: 0 – 10 vol.% for N_2 gas
3) In a long pulse test with the water flow and high-voltage load, no erosion and no corrosion of the ceramic tube were observed even after 50 hours of operation under high-leak current load (>154 mA).
4) In a high pressure test, it was confirmed the ceramic tube (100 mm dia.) could sustain high-pressure of 5 MPa which was 2.5 times higher than the nominal pressure.

The insulation performance of the developed tube was confirmed in the R&D.

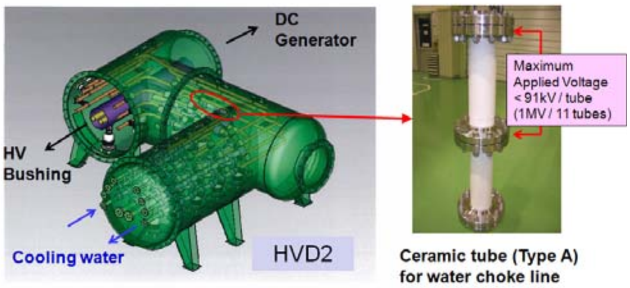

Fig. 2 Bird's eye view of HV deck2 and ceramic insulation tube for water choke line.

4. 1 MV insulating transformer

The insulating transformer supplies AC 6.6 kV power to the high voltage deck 1 (HVD1) where the negative ion source power supplies are mounted at the potential of DC - 1MV. DC - 1MV insulation in the transformer windings, output leads lines and bushing is a key issue to realize such system. R&D items are described as follows;

1) DC 1 MV insulation inside transformer between the main and edge windings, and among three phase winding leads.
2) DC 1 MV insulation between oil and air in the output bushing of the insulating transformer.
3) DC 1 MV insulation for the output leads between the winding and the bushing.

A mock-up transformer model will be fabricated and UHV insulation tests will be performed to verify the reliability of the design. These results will be reflected the fabrication of the power supply for the NBTF.

Considering the design activities and R&Ds, construction schedule of the NBTF in Padua has been discussed among ITER, EUDA and JADA and operation of the NBTF will be started in 2017.

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