The design of the residual ion dump power supply for ITER neutral beam injector

Alberto Ferro a,⁎, Elena Gaio a, Luca Sita b, Luigi Rinaldi b, Giovanni Corbucci b, Giuseppe Taddia b, Daniel Gutierrez c, Muriel Simon c, Hans Decamps d

⁎ Corresponding author.
E-mail address: alberto.ferro@igi.cnr.it (A. Ferro).

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ABSTRACT

The Residual Ion Dump Power Supply (RIDPS) is part of the Ground Related Power Supplies (GRPS) of the MITICA experiment of the ITER Neutral Beam Test Facility (NBTF) and the two ITER Heating Neutral Beam Injectors (HRBI). The GRPS will be manufactured by OCEM Energy Technology s.r.l. (OCEM) via a procurement contract with F4E. The RIDPS is devoted to feed the electrostatic Residual Ion Dump (RID), which deflects and collects the beam residual ions after the neutralization process. The maximum average voltage of the RIDPS is 25 kV, to which can be superimposed a sinusoidal or trapezoidal alternate voltage at 50 Hz, 5 kV maximum. The nominal current is 60 A, with a maximum pulse length of 1 h. This paper describes the detailed design of the RIDPS, highlighting its peculiar aspects, and the expected performance resulting from simulations.

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1. Introduction

The Ground Related Power Supplies (GRPS) for the two Heating Neutral Beam Injectors (NBI) of ITER (Cadarache, France) will include the Residual Ion Dump Power Supply (RIDPS). The RIDPS is devoted to polarize the plates of the Residual Ion Dump (RID), the beam line component which has to deflect and collect the residual ions downstream the Neutralizer [1]. The same power supply will be also provided for MITICA (Megavolt ITER Injector & Concept Advancement), the full-scale prototype of the ITER NBI, under construction in Padua (Italy) [2].

The RIDPS has to provide a voltage which is the sum of a dc component (ranging between 5 and 25 kV) plus an ac component (maximum 5 kV peak), thus the maximum peak output voltage is 30 kV [3]. The voltage ripple has to be lower than ±500 V and the maximum current is 60 A. In addition, the RIDPS has to include a fast protection against short-circuits at the output, due to possible arcs which could occur between RID plates; in such events, the arc energy has to be limited as much as possible, to avoid damages.

Different design solutions have been studied in the past for the RIDPS. For example, in [3] it was proposed a topology based on the series connection of a thyristor rectifier and a multilevel stage with 8 H-bridges. Despite some advantages, this topology was discarded because, due to the stringent ripple requirement, an important output filter would have been necessary; in case of arcs, its stored energy would be discharged on the RID plates. Therefore, a new
reference design has been developed, based on the Pulse Step Modulation (PSM) technology [4]. The advantages are: high modularity, high accuracy and, most of all, the absence of a large capacitance at the output. With PSM, in fact, thanks to the high number of modules in series and the phase-shift of the respective Pulse Width Modulation (PWM) carriers, the ripple is very limited and the output voltage regulation is very fast, thus the output filter can be much reduced. The main disadvantage of the PSM solution is the need of a transformer with many secondary windings. However, the present technology of cast resin transformers allows manufacturing such device without major issues. The PSM technology is widely used in fusion applications, however the RIDPS presents specific features which allow reducing the electromagnetic emissions and improving its reliability and availability.

The selected Industrial Supplier endorsed the PSM solution; the detailed design is being developed starting from the same technology adopted for other two power supplies provided by the same company for SPIDER ISEP5 (EGPS and RFP5, [5]). After a brief overview of the technical requirements, this paper describes the present design of the RIDPS.

2. Main requirements

The main requirements of the RIDPS are reported in Table 1. The load is represented by the RID, where the residual beam ions are deflected by the electrostatic field generated by five panels and damped on them. The field is produced by applying positive or negative potential to the two even panels, while the others are grounded locally. The RIDPS output current is essentially imposed by the beam source, with little dependence on the output voltage. Therefore, the load of the RIDPS can be approximated as a current generator. A changeover facility at RIDPS output is required to invert the voltage at RID plates, in order to test both polarities in MITICA. Therefore, both RIDPS output terminals have to be insulated for 30 kV with respect to ground.

In MITICA, the RIDPS will be connected to the 22 kV ac distribution grid by the respective withdrawable circuit breaker foreseen in the MITICA Distribution Board. At ITER Site, instead, the RIDPS shall also include a 24 kV ac disconnector and earthing switch, to be connected to the ITER 22 kV ac distribution grid.

In MITICA, the RIDPS will be installed in the MITICA Power Supply hall (Building 3), composed of two floors. The power section will be installed at the ground floor, while the Local Control System will be installed at the first floor. At ITER Site, the RIDPS of both HBNI1 and HBNI2 will be installed in Building 34, organized in two floors as in MITICA. Both Building 3 and Building 34 are far from the Neutral Beam Injector, therefore the output cable of RIDPS will be very long (in MITICA the cable length is about 150 m). This unusual situation requires the adoption of a coaxial output cable and the common-mode output filter described in the following.

3. Power section design

The topology adopted for the RIDPS is the PSM [4], with 42 power modules in series at the output, supplied by a multi-secondary cast resin transformer. Half secondary windings are star and half are delta connected, giving a current absorption from the mains with 12 pulses. The power modules are arranged in six columns and seven rows in a plastic frame, as shown in Fig. 1. Both transformer and modules are mounted on a common iron pedestal, allowing the transportation of the whole RIDPS without disassembling the 126 power cables connecting transformer and modules (Fig. 1). Therefore, the insulation test of the power modules will be performed in factory only, at 60 kVdc with an high voltage generator.

All the power modules are cooled with demineralized water by means of a couple of distribution pipes, respectively at the bottom (inlet) and at the top (return) of the frame, feeding the six module columns in parallel. The water flow on each column is monitored through a flow-switch. Thanks to the high module efficiency, the total required flow rate is less than 0.5 L/s at 10 bars with a maximum water temperature increase of 8°C.

The overall electric scheme of the RIDPS is shown in Fig. 2. The IGBTs of the power modules are commutated with a proprietary modulation algorithm called Multi Pulse Width Modulation (MPWM) [6]. The ripple frequency at the output is fixed at 84 Hz. Thanks to the phase-shift of the PWM carriers of the modules, their frequency is 2 kHz only (with 42 working modules), which is suitable for the IGBTs. The voltage ripple at the output is smoothed by a low-pass RLC output filter with the values of Fig. 2, where the inductance is a custom-made air-wound inductor and the capacitance is made of 25 capacitors (each rated for 1250 V) in series. At the return point of the output cable, at RIDPS side, an additional RC filter to ground is foreseen to shunt the common mode currents.

![Fig. 1. RIDPS mechanical layout.](image)

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