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Final design of the acceleration grid power supply conversion system of the MITICA Neutral Beam Injector

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HIGHLIGHTS

- Development of innovative high power converters based on IGCT components, based on industrial medium voltage drives.
- Development of innovative systems for the protection from internal faults in the inverters, based on fast fuses. The concept has never been used before in such applications.
- The extremely high power involved ruled out the use of conventional protection systems such as crowbars, in favor of the development of customized fuse protection.

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ABSTRACT

The Acceleration Grid Power Supply (AGPS) is a system devoted to supply the acceleration grids of the MITICA experiment, the full scale prototype of the ITER Neutral Beam Injector (NBI), being built in Padova (Italy) to test the NBI in advance of the operation in ITER. The procurement of the AGPS is split in two parts: the low voltage conversion system, namely the AGPS-Conversion System (AGPS-CS,) being procured by the European domestic agency, and the high voltage DC Generators (AGPS-DCG), being procured by the Japanese domestic agency. After the contract award, in late 2015, the executive design phase of the AGPS-CS has been finalized. The paper will present the final design of the AGPS-CS and will discuss the main choices in particular concerning the protection from internal faults of the inverters.

1. Introduction

The ITER Heating Neutral Beam Injector (NBI) [1] is rated to deliver 16.5 MW of additional heating power to the plasma, with pulse duration up to one hour. The beam acceleration is obtained by a multistage grid composed of five acceleration grids, powered by the so-called Acceleration Grid Power Supply (AGPS) [2]. The AGPS is a special switching power supply feeding around 56 MW at −1 MV dc to the acceleration grids, and able to interrupt the power delivery in some tens of microseconds in case of grid breakdown, which is a condition expected to occur rather frequently during a pulse. The challenging requirements, both in terms of ratings and of specific constraints related to the particular application, called for in-depth studies and simulations to outline the reference design of the system [3–5]. The ITER AGPS reference scheme, shown in Fig. 1 with the output nominal ratings, consists of an ac/dc stage feeding via dc links (not shown in the figure) five Neutral Point Clamped (NPC) three-phase inverters, each connected to a step-up transformer feeding a diode rectifier and a DC filter. The rectifiers are connected in series at the output side to obtain the nominal accel-

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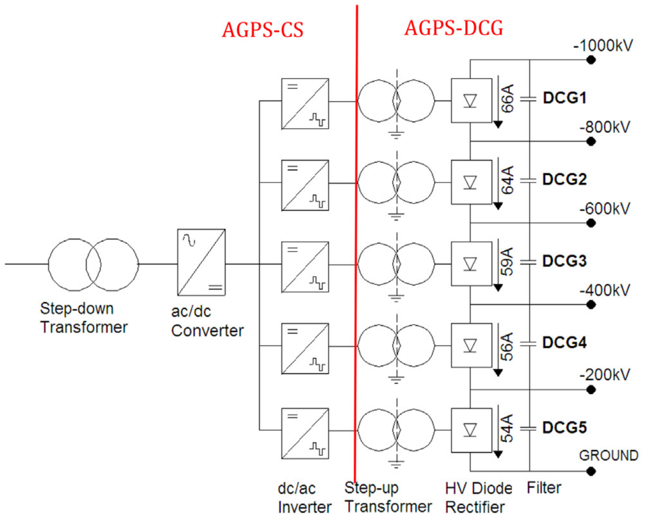

Fig. 1. AGPS reference scheme.

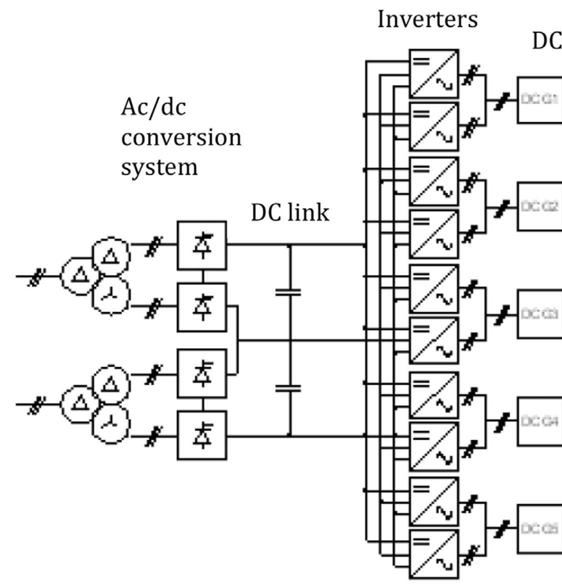

Fig. 2. AGPS-CS detailed scheme.

eration voltage of −1 MV dc, with availability of the intermediate potentials. The output of the AGPS is connected to the acceleration grids of the NBI via a SF_6 insulated Transmission Line. The procurement of the system is shared between the European Domestic Agency (F4E), which is providing the low voltage power conversion equipment, namely AGPS Conversion System (AGPS-CS), and the Japanese Domestic Agency (JADA), providing the high voltage part, downstream of the inverter units, called AGPS Direct Current Generator (AGPS-DCG) and the Transmission Line [2]. The operation of the AGPS is controlled by a dedicated control and protection system, the AGPS Control (AGPS-LC), within the scope of the AGPS-CS procurement. The interface between the procurements is critical and required the establishment of agreed interface parameters [5] in order to harmonize the design and ensure the achievement of the AGPS performance.

This paper deals with the final design of the AGPS-CS for the MITICA test facility [6], the full scale prototype of the ITER NBI. The contract for the procurement of the AGPS-CS has been awarded and launched in late 2015; presently the detailed design phase has been completed and the manufacturing phase is being launched. The reference scheme was endorsed by the manufacturer, during the development of the detailed design, particular attention was addressed to the most critical components, the Neutral Point Clamped (NPC) inverters, based on 6.5 kV Integrated Gate Commutated Thyristors (IGCTs), which must comply with severe conditions in case of internal faults, due to the large amount of energy stored in the system. The paper presents the detailed design of the AGPS-CS, discussing the main design choices and the layout of the system. The analyses performed to design the protection from the internal fault of the inverters will be finally reported.

2. Final design of the AGPS-CS

The demanding requirements in terms of power and dynamic performance called for a custom design of the AGPS-CS; developments with respect to presently available industrial solutions have been necessary especially on the NPC inverters. In particular, the special requirements impacting on the design are the increased voltage and current and the necessity of quickly cut-off the power in case of breakdowns, in order to avoid damages to the acceleration grids [5]. Since the breakdown is equivalent to a short-circuit of the load, the inverter switches must be designed to turn-off a high current (on the order of 6kA) within short times (less than 150 μs).

For the MITICA experiment, the final design led to the scheme of Fig. 2.

The input ac/dc conversion system is composed of two 38.2MVA three winding step-down transformers supplying four thyristor rectifier units connected in series at the output. Each rectifier is rated for 1625 V, 9kA dc; the output of the rectifiers supplies a common dc link at 6500 V (2 × 3250 V), with central point available for the Neutral Point connection to the inverters. The dc link capacitors are actually distributed among the inverter modules to minimize the stray inductance of the connections; the total capacitance of the dc link is 39.6mF at 6500 V (79.2mF at 3250 V). Each of the five dc/ac conversion stages are composed of two three phase NPC inverters connected in parallel, based on the Integrated Gate Commutated Thyristor (IGCT) semiconductor. Each inverter is rated for 5500Vrms, 850Arms and can modulate the output voltage in square-wave at a switching frequency of 150 Hz, providing a phase-to-phase voltage amplitude of 6500 V. The equivalent apparent power of each dc/ac conversion stage is about 16MVA. Each inverter can switch-off a current of 3kA (6kA in total for the stage), corresponding to the maximum expected current during a breakdown. At the output of each inverter an inductance of 90 μH is connected, both to improve the current sharing and to limit the current derivative in case of breakdown. Finally, five medium voltage, 240 mm^2 cables per phase for each dc/ac conversion stage (15 cables per stage in total) will be installed to connect the AGPS-CS to the AGPS-DCG. The AGPS-CS can be isolated from the AGPS-DCG by means of disconnector switches placed downstream of dc/ac conversion stage.

2.1. Ac/dc thyristor rectifier

The ac/dc thyristor rectifier unit (1625 V, 9kA dc) is a six-pulse bridge with four thyristors in parallel per arm. The thyristors are individually protected by a fuse and RC snubber; each thyristor is mounted on heat sink and double side cooled with deionized water; fuses are cooled also in the same way. The thyristor component has been specifically developed for this application and is derived from the standard ABB Semiconductor component 5STP34N5200. The rectifier unit has been designed assuming a current unbalance between thyristors of 25% during normal operation and can actually work with three thyristors in parallel for a reduced number of typical pulse cycles.