Contribution ID: **751** Type: **Regular Poster**

Power Supply Commissioning to achieve DC Power Control for Superconducting Coils in JT-60SA

Wednesday 12 May 2021 08:50 (20 minutes)

The commissioning of the power supplies for superconducting coils in JT-60SA has been done with dummy load (Inductance: 7.64 mH, Resistance: 6.995 mΩ) since June 2019. The most important results are that (i) Integrated operation of the different PS components was completed successfully, (ii) High voltage generation of the rated voltage of 5 kV by Switching Network Unit (SNU) was performed properly and (iii) DC current interruption with rated current of 20 kA by Quench Protection Circuit (QPC) was achieved. These results are a prerequisite to achieve the integrated power supply operation with superconducting coils in JT-60SA and, in a next stage, contribute to the power supply commissioning of ITER and DEMO.

The detailed design of power supplies to provide the needed DC power to Toroidal Field (TF) and Poloidal Field (PF) superconducting coils for JT-60SA was started from 2011 and the installation and individual test for each power supply component has been completed by 2018, with a strong collaboration between Japan and EU. Each PF circuit consists mainly of three power supply components: the "Base PS"ac/dc thyristor converters for steady-state operation with low voltage (~ 1 kV) and high current (20 kA) ratings, the SNU and the QPC. In addition, the PS system includes the Motor Generator and a set of Vacuum Circuit Breakers providing the ac high voltage to the Base PS, the low voltage auxiliaries and the water cooling system. It is essential to verify the performance of the overall system using dummy load before real plasma experiment with superconducting coils in JT-60SA. To this aim, the commissioning for each PF circuit was performed by a dedicated supervisory control system which was newly developed for JT-60SA to achieve high-speed (4kHz) and real-time control of power supplies [A].

The main goal of these combined tests was to verify that the different power supply systems, which were individually tested, could work together in a coordinate way, following the time sequence, the commands and the references generated by the supervisory control system, both in normal operation and in case of fault, activating the correct and coordinate protection sequence when required. During the performance of the combined tests, it has been found that the implementation of the time sequence was not homogeneously programmed in all devices, causing unexpected operations, and it has been necessary to modify the firmware of some components. Thanks to these improvements, it has been possible to perform a complete 20 kA pulse on a PF circuit connected to the dummy load, with the coil current shape provided by the Base PS according to the assumed plasma scenario, and with the correct operation of the SNU and the QPC.

Figure 1 show current and voltage shapes indicating SNU operation at t=0s and also QPC operation by a simulated quench signal.
The SNU [B] is necessary to generate the high voltage (5 kV) required for plasma ignition. This is obtained by pre-charging the coil up to the nominal current of 20 kA, then inserting in the circuit a resistor with pre-settable value, obtaining a fast current variation, and finally by-passing the resistor when the plasma ignition is obtained. This function is managed by the operation of a hybrid switch for DC current interruption and requires a close coordination with the operation of the Base PS.
The QPC [C] has the function to protect the superconducting coil by dissipating the large energy stored in the coil inserting in the circuit a dump resistor in the case of coil quench or other faults requiring a fast discharge, with the requirement to complete the 20 kA DC current interruption in 350ms. The QPC main components are a hybrid switch for DC current interruption, a pyrobreaker (explosive fuse) for backup, and a dump resistor for coil energy consumption.
It was observed that the SNU can interrupt circuit current of 20 kA to commutate its current to the SNU resistor and can generate 5 kV against the coil in plasma ignition phase. Moreover, it was also observed that the QPC can interrupt the circuit current properly by the simulated quench signal. This result is that the system combined with the Base PS, the SNU and the QPC can operate properly.

In addition, during the combined tests it has been possible to verify the correct operation of the SNU and the QPC with nominal current provided by the Base PS, reaching their maximum rated voltage. These tests were already performed in factory, but not yet repeated after the on-site installation, due to the unavailability of a PS rated for 20 kA at the time of the individual commissioning. Indeed, some problems due to a wrong connection of a voltage transducer in the QPC have been detected when operating at current higher than 10 kA and solved by modifying the connection layout.

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Session Classification: P3 Posters 3

Track Classification: Fusion Energy Technology