IMPROVEMENTS OF MAGNET POWER SUPPLY SYSTEM AND ACHIEVEMENTS IN COIL ENERGIZATION TESTS FOR FIRST PLASMA OF JT-60SA

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Three improvements of superconducting magnet power supply (PS) system were conducted after EF1 coil incident [1] caused by insulation failure during JT-60SA integrated commissioning in 2021. The main target of the improvements was to reduce the voltage to ground at the coil terminal and to suppress overvoltage across the coil from the viewpoint of coil insulation. The performance after each improvement was verified by power test with a reused dummy load (inductance: 7.64 mH, resistance: 6.995 mΩ) From the results, it was confirmed that these improvements are advantageous for safety operation to reduce the voltage to ground at the coil terminal by almost half in normal operating condition, and to suppress the overvoltage across the coil less than 2.7 kV in conformity with the validated coil insulation performance. After the improvements of magnet PS system, the coil energization test with superconductive coils in JT-60SA integrated commissioning was started in August 2023. As a result, it was confirmed that all the PS components, such as Base PS [2], Switching Network Unit (SNU) [3], Booster PS [4] and Quench Protection Circuit (QPC) [5], could be operated as expected under the rated current of 25.7 kA for toroidal field coils (TFCs) and +/–5 kA for poloidal field coils (PFCs) set as the operation range of Operation-1 phase (Tab. 1), considering the validated coil insulation performance. With the successful coil energization test, the first plasma of JT-60SA could be achieved successfully.

Tab. 1. Required and achieved operation range of Operation-1 phase.

Coil		Design Rating	Operation-1 (required and achieved)
PFC	CS1–4, EF3/4	+/–20 kA, +1/–5 kV	+/–5 kA, +1/–2 kV
	EF1/2/5/6	+10/–20 kA, +/–5 kV	+/–5 kA, +/–2 kV
TFC	TF1–18	25.7 kA, +80 V/–1.93 kV	25.7 kA, +80 V/–1.93 kV

The followings are the details of the improvements after EF1 coil incident;

(I) MOVEMENT OF THE GROUNDING POSITION IN PFC CIRCUIT

In the magnet PS system for PFC, Base PS, SNU/Booster PS and QPC are connected in series. In the original configuration, the grounding position of PFC circuit was at the mid-point of output terminals of Base PS. In this case, almost full output voltage generated by SNU/Booster PS or QPC appeared at one side of coil terminal as voltage to ground when it was activated. This phenomenon might cause a significant stress on the coil insulation, which finally would lead to a breakdown. For this reason, the grounding position of all PFC circuits including EF1 was moved to the mid-point of coil from the one of Base PS. With this modification, the voltage to ground at each terminal of the coil in normal operating condition could be almost half of the output voltage of PS system.

(II) INSTALLATION OF VOLTAGE RIPPLE REDUCTION FILTER FOR BOOSTER PS

Booster PS is used for plasma initiation and shape control for EF1/2/5/6 coils (outer PFCs). It was reused from previous JT-60U, and has a large voltage ripple of 4 kVp-p superimposing on the maximum nominal operating voltage of +/–5 kV. To reduce this voltage ripple, a filter with 2nd order delay was installed in parallel to Booster PS. The filter consists of two capacitors, a resistor and a current limiting reactor. The cut-off frequency of the filter was set at 90 Hz considering the worst gain reduction at the lowest ripple frequency of 325 Hz. For the effect of the installed filter, the voltage ripple across the coil could be reduced to 400 Vp-p.

(III) INSTALLATION OF VARISTORS AT PFC CIRCUIT

After EF1 incident, the ground fault power test with dummy load showed that 1.7 times higher peak voltage than the output voltage of PS system appeared at one side of coil terminal by transitional resonance due to stray capacitance and inductance of PFC circuit in the case of ground fault. To suppress this overvoltage, the varistor having voltage clamping function was installed at each side of coil terminal. Considering the worst result at 2.8 kV in the withstand voltage test for coil under Paschen discharge condition before Operation-1 phase, the selection of varistor type and the installation to all PFC circuits were carried out. With this improvement, it was confirmed that the overvoltage in the case of ground fault could be suppressed to 2.7 kV from 3.4 kV under 2 kV operating condition, which was assumed for Operation-1 phase.

In coil energization test with superconductive coils in JT-60SA, the individual coil energization test was carried out to confirm the performance of each magnet PS component at first. The individual TFC energization test was performed with increasing the current in stages to the rating at 25.7 kA. This test included QPC activation test, temperature rise measurement in transformer windings and AC cables, etc. during long energization of TFC. In addition, pyrobreaker (explosive circuit breaker for backup device in QPC) operation at 15 kA was also conducted. The individual PFC test was carried out within the operation range of the voltage of +/–2 kV and the current of +/–5 kA. This test included QPC activation test and SNU / Booster PS operation at +/–2 kV, and was performed with increasing the current step by step. After the successful completion of the individual coil energization test, the integrated coil energization test was performed step by step increasing the number of superconductive coils in simultaneous operation. Furthermore, the integrated coil energization tests were performed in two phases changing the current and voltage limitations for PFC because of their validated electrical insulating performance. The first phase was up to +/–3 kA and +/–1 kV for first plasma, and the second one was up to +/–5 kA and +/–2 kV for higher current divertor plasma. Based on the first plasma scenario, it was confirmed that all PFC/TFC could be successfully energized simultaneously (Fig. 1).

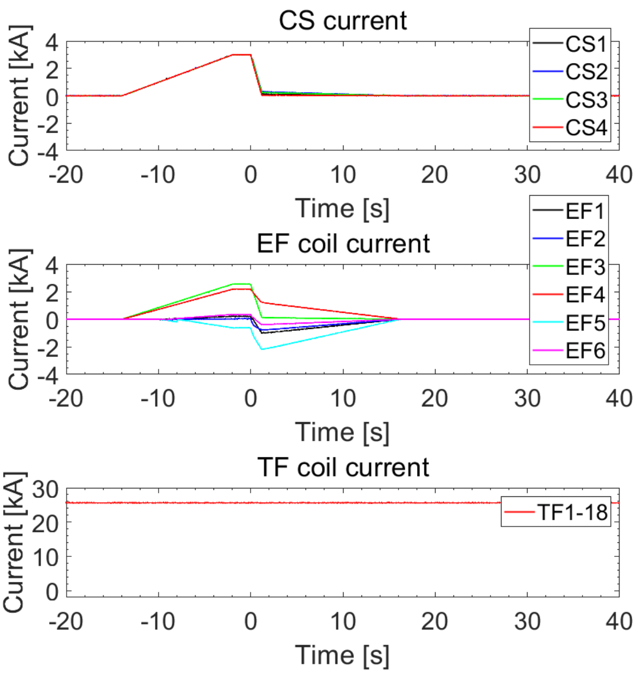

Fig. 1. Integrated all PFC/TFC energization test without SNU/Booster PS based on first plasma scenario
(a) Current waveforms of CS1–4 (b) Current waveforms of EF1–6 (c) Current waveform of TFC at the constant full current of 25.7kA.

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