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Improvements of Magnet Power Supply System and Achievements in Coil Energization Tests for First Plasma of JT-60SA

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ABSTRACT

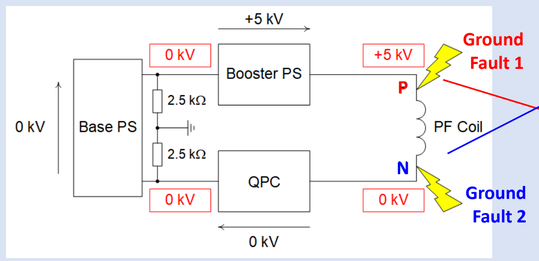
- Three main improvements of superconducting magnet power supply (PS) system to reduce the voltage to ground at the coil terminal were implemented following the EF1 coil incident caused by insulation failure during JT-60SA integrated commissioning in 2021.
- After the improvements of magnet PS system, the coil energization test with superconductive coils in JT-60SA integrated commissioning was safely restarted and successfully completed.
- All the magnet PS components were confirmed to operate as expected within the operational range defined for Operation-1.

BACKGROUND

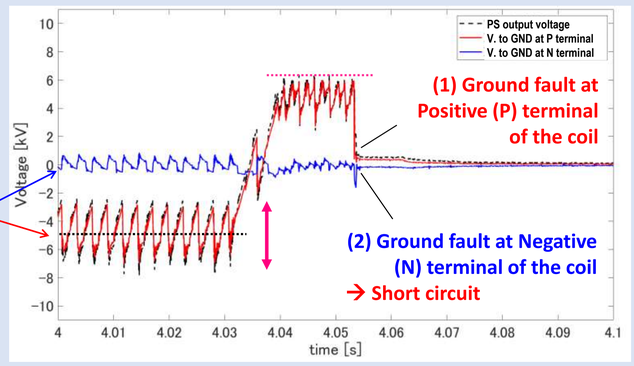
- First integrated commissioning of JT-60SA in 2021 was suspended due to short circuit incident (double ground fault) at the joints of EF1 superconducting coil.
- For enhancing reliability, reducing risk and preventing reoccurrence, it has been decided to implement three main improvements in magnet PS system.

Features of voltage to ground in Booster PS operation in 2021

1. Almost full PS output voltage appeared at Positive (P) terminal
2. Large voltage fluctuation (ripple)



Potential distribution during Booster PS operation



Waveforms of coil terminal voltage to ground at EF1 coil incident in 2021

IMPROVEMENTS OF SUPERCONDUCTING MAGNET PS

(i) Movement of the Grounding Position in Poloidal Field Coil (PFC) Circuit

Before: Mid-point of Base PS → After: Mid-point of superconducting coil

Terminal voltage to ground could be equalized across both terminals of coil, resulting in only half of the output voltage of PS system

(ii) Installation of Voltage Ripple Reduction Filter for Booster PS

Large voltage fluctuations (ripples) superposed on DC output voltage of thyristor converter in principle (f > 325 Hz for the case of JT-60SA).

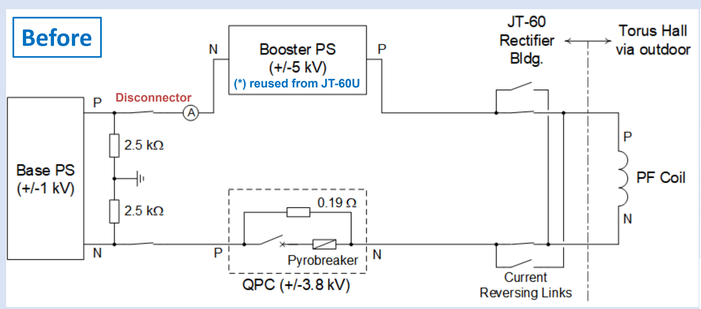
Thanks to the installed filter (cut-off frequency at 90 Hz), the voltage ripples could be reduced to 1/10.

Before: +/-2 kV → After: +/-200 V

(iii) Installation of Varistors in PFC Circuit

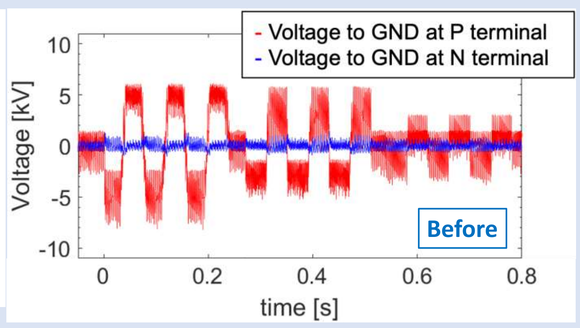
At instant of ground fault, a fast voltage oscillation appears on the other terminal due to transitional resonance caused by stray capacitance and inductance of circuit.

Before: 3.4 kV(peak) → After: 2.7 kV(peak) (at nominal 2.0 kV operation)

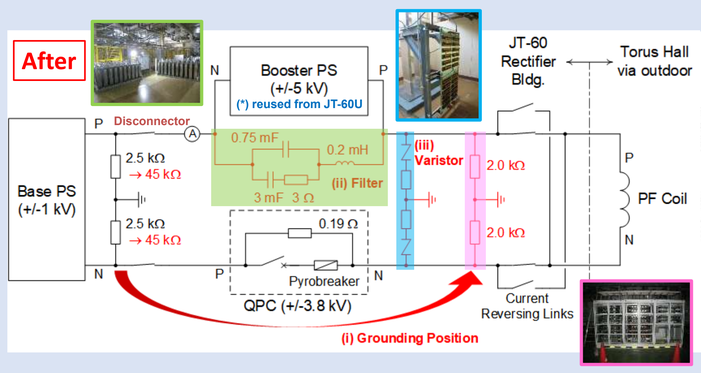


Simplified PFC PS Circuit Before Improvements

➢ Almost full PS output voltage appeared at Positive (P) terminal of coil



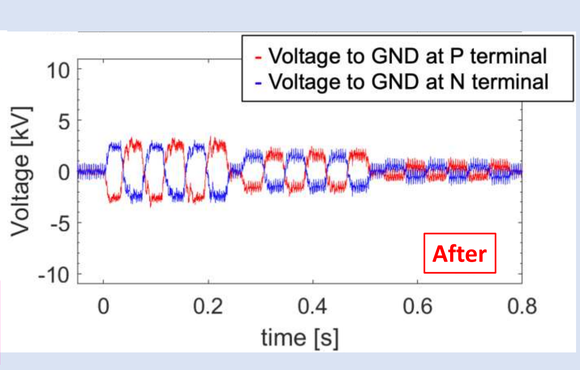
Waveforms of voltage to ground Before Improvements
(Booster PS output at +/-5 kV, +/-3 kV, +/-1 kV and w/ Dummy load coil)



Simplified PFC PS Circuit After Improvements

➢ Terminal voltage to ground could be equalized across both terminals of coil

➢ Large voltage fluctuations (ripples) could be reduced significantly



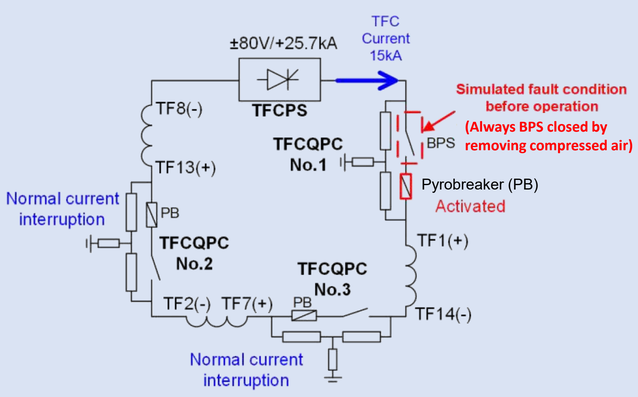
Waveforms of voltage to ground After Improvements
(Booster PS output at +/-5 kV, +/-3 kV, +/-1 kV and w/ Dummy load coil)

→ **Coil energization tests of JT-60SA could be restarted more safely**

COIL ENERGIZATION TESTS

(1) INDIVIDUAL COIL ENERGIZATION TESTS

- Initially, the individual coil energization tests were performed on the superconductive magnets to confirm the performance of each coil PS component.

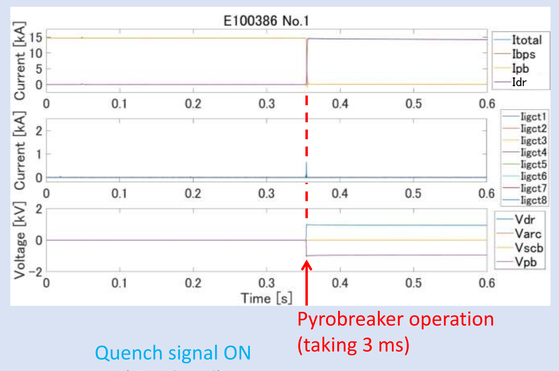


Simplified TFC PS Circuit

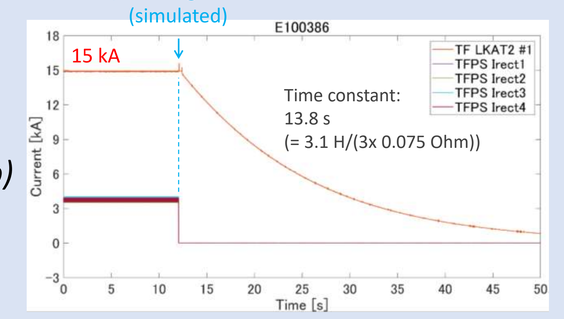
◆ Successful Pyrobreaker operation was confirmed with real TFC at 15 kA.

→ Since Pyrobreaker solution as backup coil protection is applied not only to JT-60SA but also to ITER, this achievement and the gained operation experience are important contributions to ITER by JT-60SA.

(a)



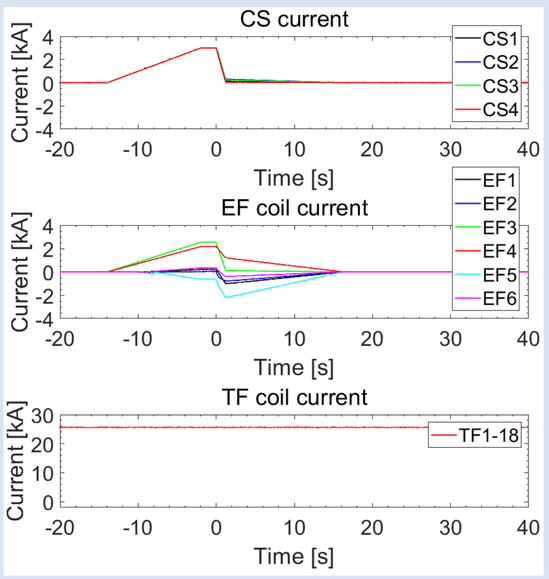
(b)

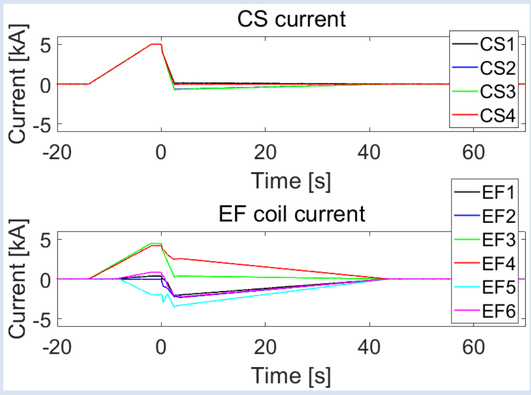


Individual Pyrobreaker test with real TFCs
(a) Current and voltage waveforms of Pyrobreaker operation in TFC QPC No.1 with simulated BPS fault,
(b) Current waveforms of TFC and each rectifier in TFC PS.

(2) INTEGRATED COIL ENERGIZATION TESTS

- After the individual coil energization tests, the integrated coil energization tests were performed step by step progressively increasing the number of superconductive coils in simultaneous operation.





All PFC integrated energization test with SNU/Booster PS (Max: ±5 kA, ±2 kV)
(*) TFCs were not energized to avoid unexpected fast discharge triggered by a false quench detection due to induced noise.

All PFC/TFC integrated energization test without SNU/Booster PS (Max: ±3 kA, ±1 kV)

◆ Based on the current scenario assumed to obtain the first plasma, all PFCs/TFCs could be successfully energized simultaneously.

→ **Ready for First Plasma**

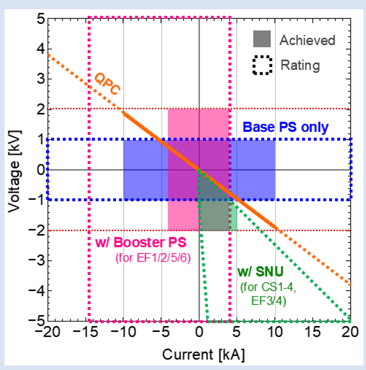
◆ All PFCs could be successfully energized simultaneously with expected operation of SNUs/Booster PSs.

→ **Ready for Higher Current Plasma**

CONCLUSIONS

- Three improvements of superconducting magnet PS system were conducted before the restart of Integrated Commissioning.
- In the restarted Integrated Commissioning/Operation-1, the expected operation of all PS components including Pyrobreaker and the consequent expected coil energization were confirmed.
- In Operation-1, the magnet PS system successfully contributed to achieve the first tokamak plasma (I_p ~130 kA), and later higher current plasma (I_p ~1.2 MA).

PFC



◆ Integrated operation of PFC PSs were limited up to +/-5 kA and +/-2 kV due to the insulation performance of the coils in Operation-1 phase.

◆ Only in individual PFC energization test at the end of Operation-1 as preparatory tests towards Operation-2, Base PSs and QPCs (w/o SNUs/Booster PSs) were tested up to +/-10 kA with superconducting PFCs (except CS3 and EF2 due to their limited electrical insulating performance).

Achieved operation range in JT-60SA integrated commissioning/Operation-1