Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 22, 2009

Fault Analysis of ITER Coil Power Supply System

Inho Song[a*], Jun Tao[a], Ivone Benfatto[a], Electrical Engineering Division[a]
[a]*ITER Organization, EED/CEP, CS 90 046, 13067 St Paul Lez Durance, France*
[*]*Corresponding author: inho.song@iter.org*

1. Introduction

The ITER magnet coils are all designed using superconductors with high current carrying capability [1]. The Toroidal Field (TF) coils operate in a steady-state mode with a current of 68 kA and discharge the stored energy in case of quench with using 9 interleaved Fast Discharge Units (FDUs). The Central Solenoid (CS) coils and Poloidal Field (PF) coils operate in a pulse mode with currents of up to 45 kA and require fast variation of currents inducing more than 10 kV during normal operation on the coil terminals using Switching Network (SN) systems (CSs, PF1 and 6) and Booster and VS converters (PF2 to 5), which are series connected to Main converters. SN and FDU systems comprise high current DC circuit breakers and resistors for generating high voltage (SN) and to dissipate magnetic energy (FDUs). High transient voltages can arise due to the switching operation of SN and FD and the characteristics of resistors and stray components of DC distribution systems. Also, faults in power supply control such as shorts or grounding faults can produce higher voltages between terminals and between terminal and ground. Therefore, the design of the coil insulation, coil terminal regions, feeders, feedthroughs, pipe breaks and instrumentation must take account of these high voltages during normal and abnormal conditions. Voltage insulation level can be defined and it is necessary to test the coils at higher voltages, to be sure of reliable performance during the lifetime of operation.

This paper describes the fault analysis of the TF, CS and PF coil power supply systems, taking account of the stray parameter of the power supply and switching systems and inductively coupled superconducting coil models. Resistor grounding systems are included in the simulation model and all fault conditions such as converter hardware and software faults, switching system hardware and software faults, DC short circuits and single grounding faults are simulated. The occurrence of two successive faults is considered for the TF coil power supply and CS/PF coil power supply systems taking account of a single fault. The analysis results are discussed for transient and steady-state during normal and abnormal operations.

2. Fault Analysis

The Coil Power Supply (CPS) systems are designed to limit the high voltages for protecting the magnets, but under the certain conditions and faults, voltages can rise above 20 kV in certain coils. Therefore, the magnet must be designed to have certain insulation level and the high voltage tests (insulation test) of coils and CPS systems have to be conducted at higher voltages.

2.1 Coil Power Supply Systems

Functions of the CPS is to provide controlled DC current and voltage to each coils for plasma initiation and shape control and to protect the superconductive magnets by a fast discharge in case of a quench. The CPS system consists 900 V (no load) converter for TF coils and 1.5 kV Main converters, 6.0 kV VS converters, 4.2 kV Booster converters and 10 kV Switching Network Unit (SNU) systems for CS/PF coils. The Main converter produces the voltage for plasma shape and position control and a fraction of the plasma initiation voltage. The SNU produces the high voltage needed for plasma initiation and is replaced by the Booster converter for the PF2~5 coils. Fig 1 shows the block diagram of pulsed power electrical network and coil power supply system.

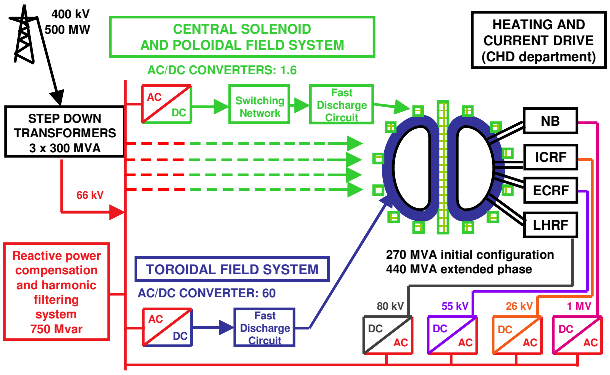

Fig. 1. Block diagram of pulsed power electrical network and coil power supply system.

The grounding system consists of series-connected resistors parallel with the coil and the midpoint of series connection is grounded through a resistor. Wit this configuration, the potentials of the two terminals of each coil terminal to ground voltage is reduced to half of the voltage across the terminals. In case of a ground fault, the terminal voltage to ground increases by a factor of two, up to the voltage across the terminals. The leak current to ground will be measured and used for ground fault protection.

2.2 Simulation Model

The PSIM software tool used for the analysis and includes all stray parameters of electrical systems such as stray inductance, capacitance and resistance of DC busbars, switching systems and resistors. Fig 2 shows the simulated circuit diagram of PF2~5 CPS system.

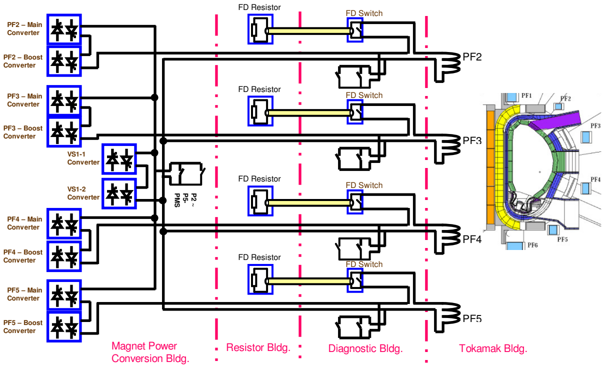

Fig. 2. Simulation model of PF2~4 CPS system.

The ripple in the AC/DC converter considered the stray parameters of DC busbars also simulated to check the transient and steady-state voltages during normal and abnormal operation.

2.3 Normal Operation

The maximum voltages introducing on coil terminals and coil terminal to ground in normal operating conditions are simulated. Considered operation conditions are as follows; 1) FDU opening, 2) jitter between switches, 3) converter maximum output. In case of TF coil power supply system, the maximum voltages between terminals to ground are 7.3 kV in transient and 3.8 kV in steady-state due to the stray parameters in the circuit. CS1U&L coils shows 7 kV in transient and 5.8 kV in steady-state and PF2~5 coils show 8 kV in transient and 6 kV in steady-state.

2.4 Fault conditions

Several fault conditions and combinations considered to determine the maximum voltage inducing in fault conditions. Considered fault conditions are as follows; 1) FDU opening failure (especially for TF FDUs), 2) converter control fault, 3) SN failure, which means control failure and 4) single grounding fault. In case of TF coil power supply systems, maximum fault voltage occurred when there is a ground fault and a FDU opening failure and is 14 kV. Peak value is reached in a steady-state and do not depend on stray parameters. Moreover, they do not depend on grounding resistance values. Concerning CS1U&L coils, the highest fault voltage is 27 kV when the FDU operates and simultaneously ground fault occurs during SDU keeps opening (SDU control fault). Fig. 3 shows the simulation result of CS1L coil terminal to ground voltage in worst fault condition. PF2~5 coil system consists of Main converter series-connected with Booster converter and parallel-connected 6 kV on-load (8 kV no load output voltage) voltage rating VS1 converter system. The peak fault voltages of PF2~5 coils system are 24 kV in transient and 24.1 kV in steady-state. Double fault cases are simulated such as converters set to their maximum values (with Booster converter), coil currents set to 10 kA, FDU opening and single ground fault.

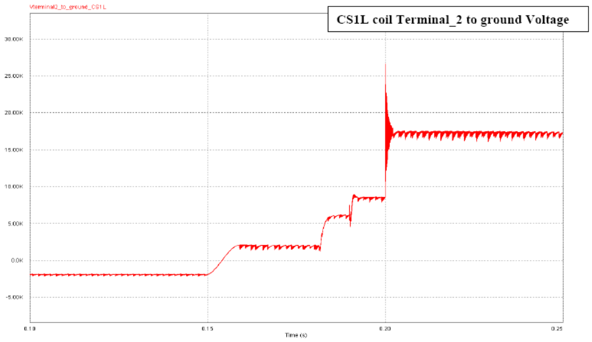

Fig. 3. The highest fault voltage when the maximum negative voltage of the converters and opening of SNU and FDU simultaneously with a single ground fault.

3. Conclusions

High voltages in the ITER coils can occur either due to plasma operation or fault conditions. The highest voltages during plasma operation occur at plasma initiation phase and the highest fault voltages are shown when the hardware fault happens before/after single ground fault. The design voltages to be taken into account are simulated under all fault conditions. The peak voltage is reaching 14 kV in TF coils and 27 kV in CS1U&L coils and 24.1 kV in PF2~5 coils. These results depend strongly on stray parameters, especially the FDU parameters (for example, it has been seen that the cable inductance between FDU and discharge resistor increases the voltage overshoot).

The coil power supply systems are designed to limit the high voltages, but under certain conditions coil terminal to terminal voltage and terminal to ground voltage can increase above 27 kV. Therefore, the acceptance tests of the systems must be carried out at higher voltages and High dielectric strength must be included in insulation design to minimize the risk of coil failure and increase the safety and availability.

REFERENCES

[1] N. Mitchell, D. Bessette, R. Gallix, C. Jong, P. Libeyre, C. Sborchia and F. Simon, The ITER Magnet System, IEEE Trans. Applied Supercond., submitted for publication in 2008.

[2] P.L. Mondino, T. Bonicelli, V. Kuchinskiy and A. Roshal, ITER R&D: Auxiliary Systems: Coil Power Supply Components, Fusion Eng. Des., Vol.55, p.325, 2001.

[3] N. Mohan, T. M. Underland, and W. P. Robbins, Power Electronics: Converters, Applications, and Design, 2nd edition, New York: Wiley.

[4] C. Neumeyer, Fast discharge options for tokamak physics experiment Toroidal field & poloidal field superconducting magnets, 40-9308270, PPPL.

[5] I. Benfatto, DC breaking tests up to 55 kA in a single vacuum interrupter, IEEE Trans. Power Del., Vol.3, no.4, p.1372, 1988.