LTS – HTS Hybrid Dipole Magnet Quench Protection System

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- Protection of Hybrid magnet.

- Operation of hybrid magnet system presents unique challenge due to interaction between two coils powered separately.

- Develop fast and reliable quench detection.

- Develop very fast energy extraction system for each coil during quench.

- Develop fast data logger system to capture transient data during quench.

- Study cross coupling of energy during quench

- Test results of the system at 4.3K

- Oral presentation by Ramesh Gupta Or28-05 (10AM Th.) discussing trapped field, magnetization effects etc.

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Hybrid Magnet

- LTS Outer coil: Two racetrack coils each with 100 turns of Nb_3Sn Rutherford cable. 10.2T at 10.8kA

- HTS insert coils: Two racetrack coils each with 35 turns of 12mm ReBCO tape from ASC and total conductor length of about 100m.
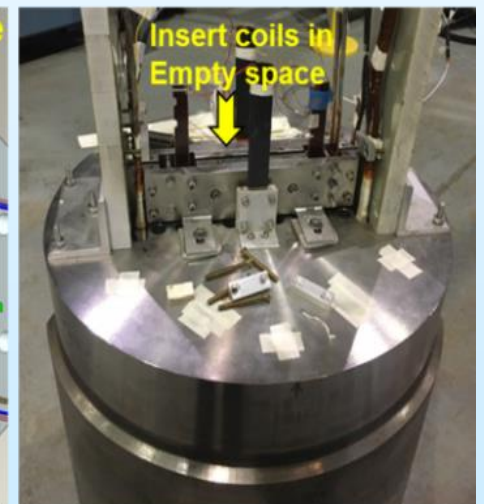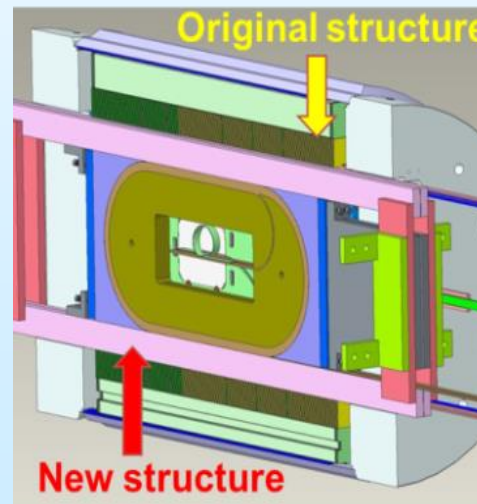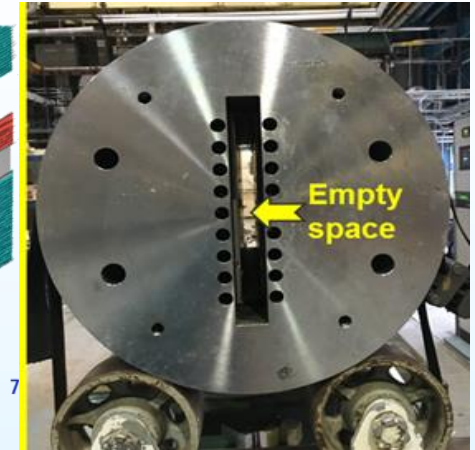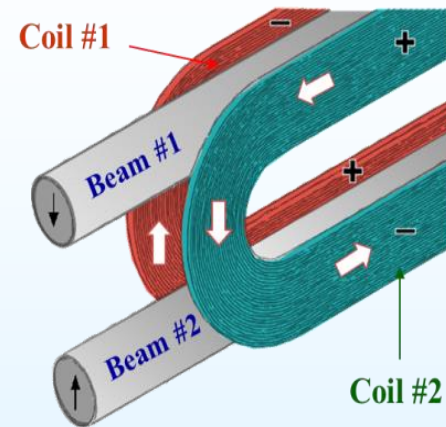
# Quench Protection System block diagram
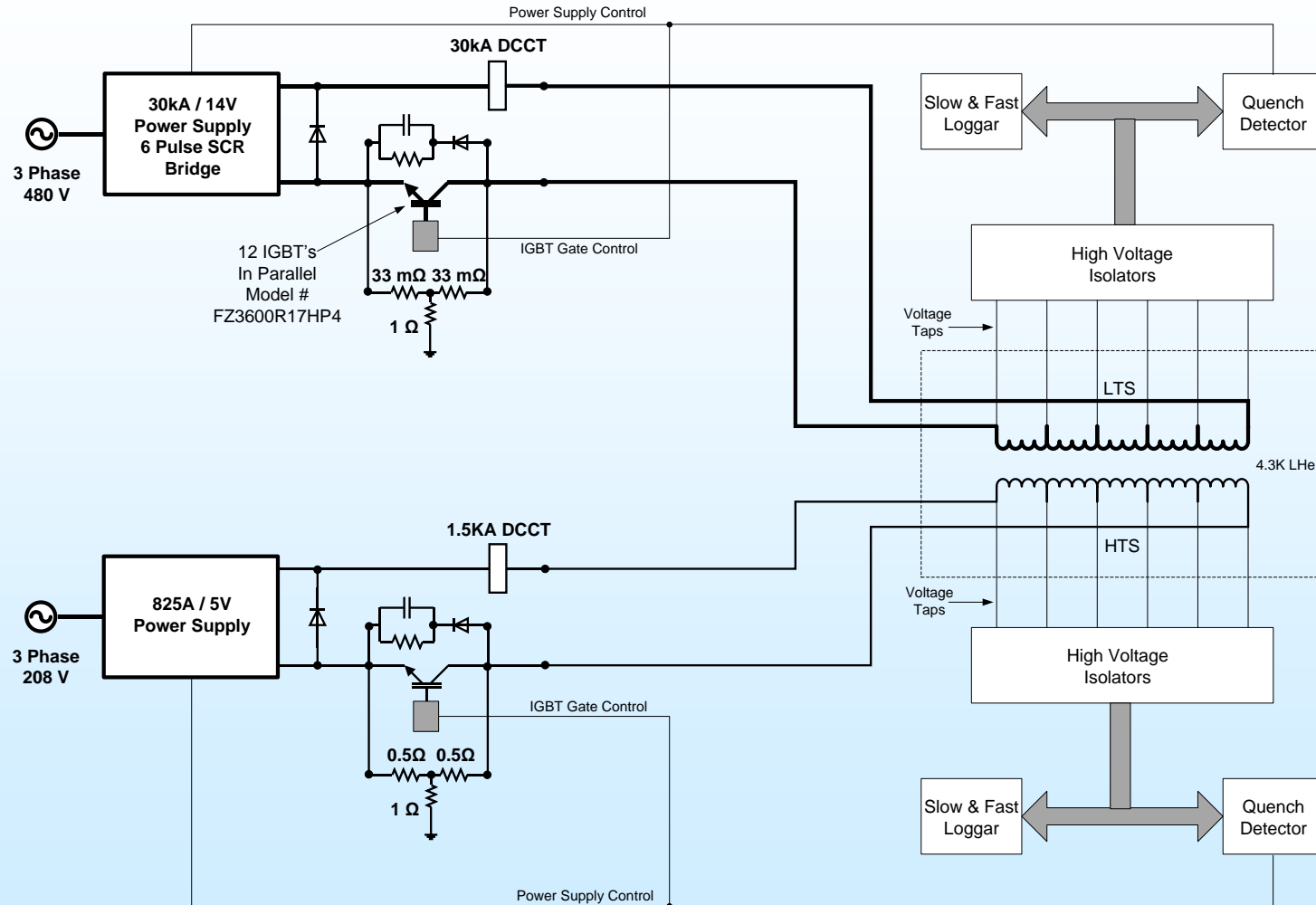
Quench Detectors

- ## HTS Quench detector :
  - Low threshold and fast detection
  - Novel technique uses counter to count successive half coil voltage difference samples above threshold up to validation time.
  - If in between samples are below threshold, counter resets
  - Threshold as low as 50mV and validation time as low as 5ms
  - Total coil voltage minus Ldi/dt voltage compared to threshold
  - Voltage tap signals sampled at 1kHz

- ## LTS Quench detector:
  - Digital system similar to HTS quench detector
  - QD threshold of 125mV and validation time of 5ms

- Both detector share common hardware but control separate power supplies and energy extraction systems

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Quench detector hardware

- Digital system based on National Instruments real time controller hardware and LabView programming language

- 16 channel, differential input, 16bit simultaneous sampling ADC modules. Model PXI 6123

- 8 channel optically isolated digital output to trigger fast logger, trigger energy extraction systems and shut off power supply

HTS quench voltage

Coil A Voltage (V)
Coil B Voltage (V)

Volts

seconds
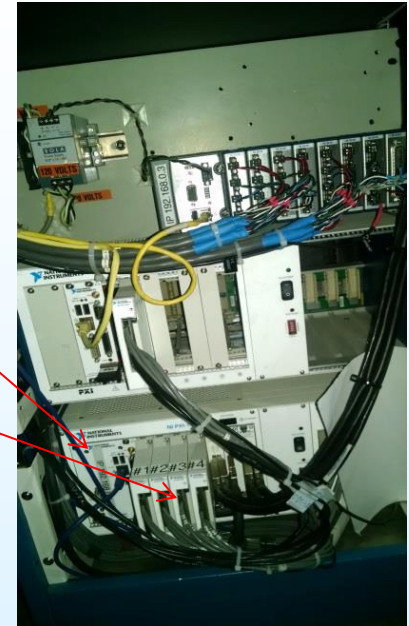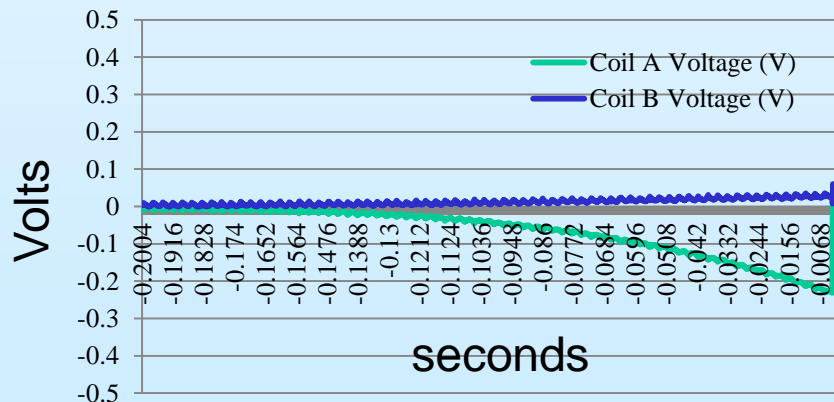
Fast and Slow Data Logger

- NI Real Time PXIe controller

- 64 channels, differential input, 16 bit simultaneous sampling at 10kHz. Model PXIe 4300 ADC modules

- Small signal analog isolators from VeriVolt with Ch to Ch isolation of 1500V and Ch to ground isolation of 2000V

- 32 channel, differential input of 16bit multiplexed Analog to Digital converter

- Sampling frequency of 1kHz and three power line cycle filtering
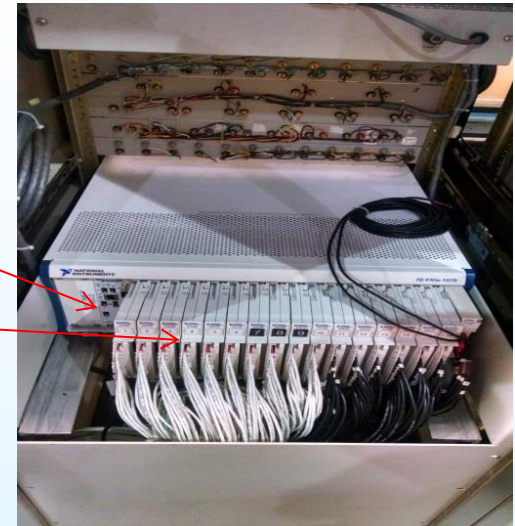
LabView Software modules

- Power supply control program

- Instrumentation and cryogenic control program

- Quench Detection program

- Energy Extraction system monitoring and control

- Data capture and analysis

- $\int(I^2\ dt)$ Calculations

Energy Extraction system

- LTS energy extraction:
  - Triggered by 24kA IGBT switch
  - 66 mΩ dump resistor
  - Extraction time delay of 2ms
  - Details of this switch in Po4.09-12

- HTS energy extraction
  - Triggered by single 2kA IGBT switch
  - 1 Ω dump resistor
  - No delay

- Charging sequence
  - LTS brought up to operating current (8kA)
  - HTS is then ramped at slow ramp rate till quench

- Discharging sequence
  - At HTS quench, open the HTS EE switch instantly and command PS to turn OFF
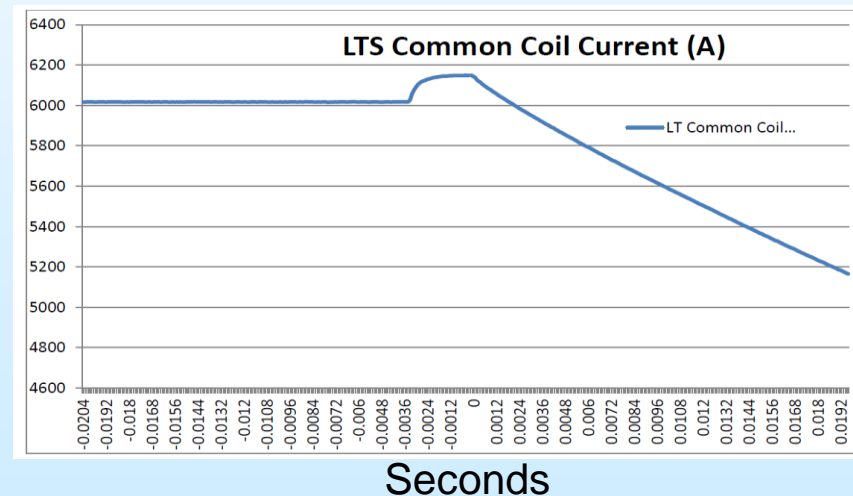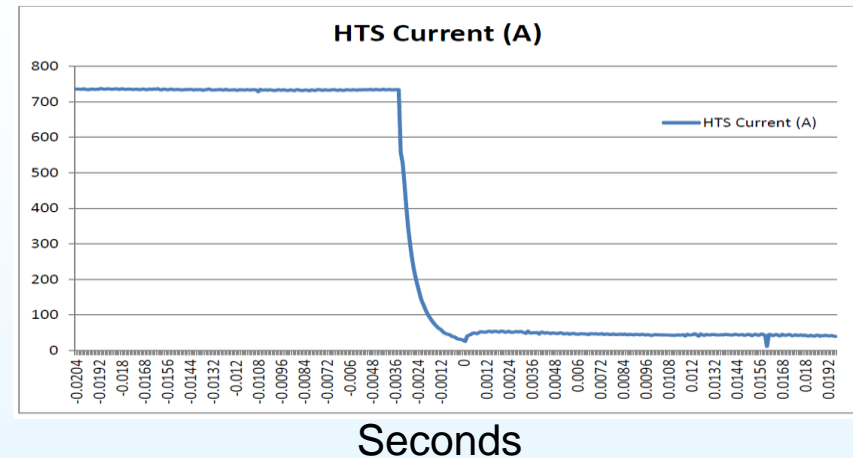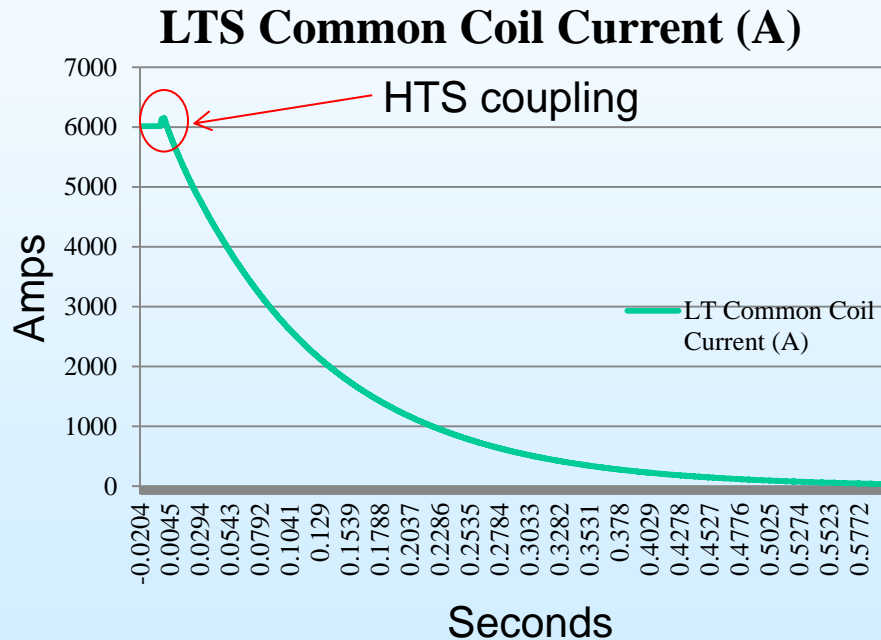 - LTS EE Switch opened after 3ms delay and heaters fired, PS turned OFF
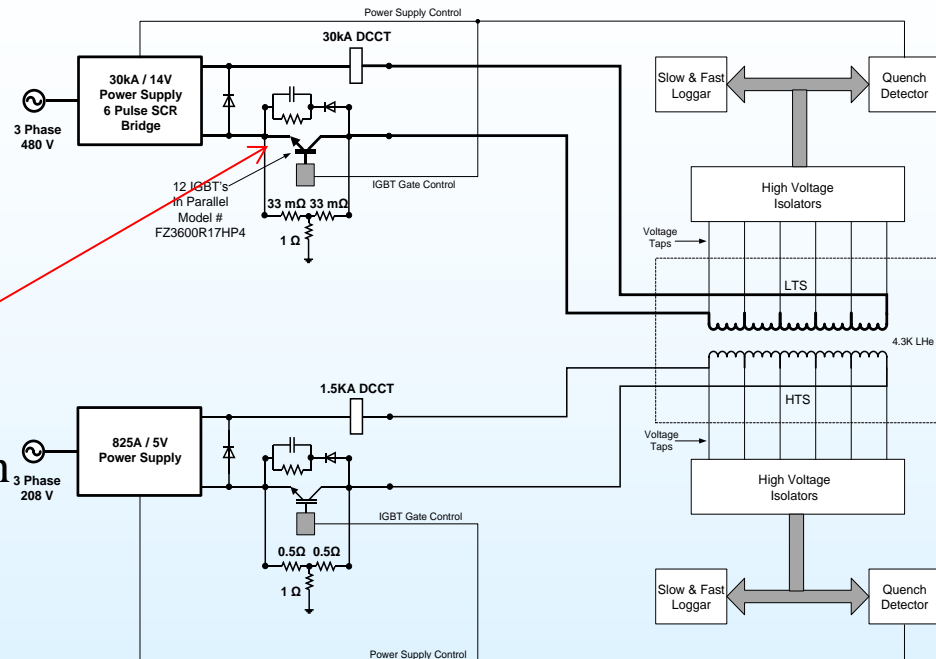
➡ Key is rapid energy extraction from HTS before LTS
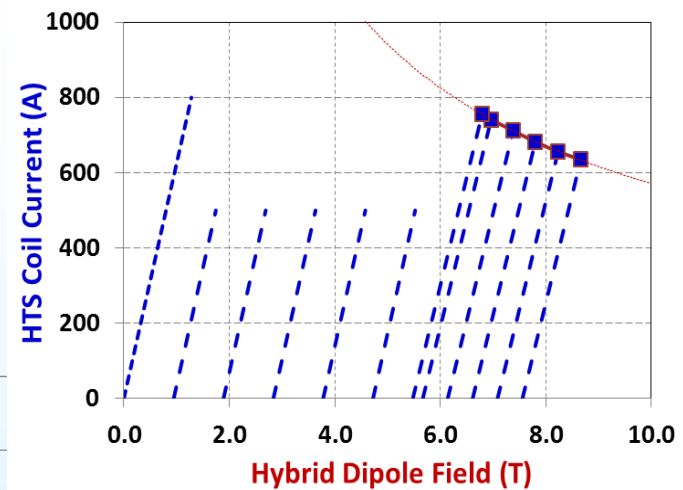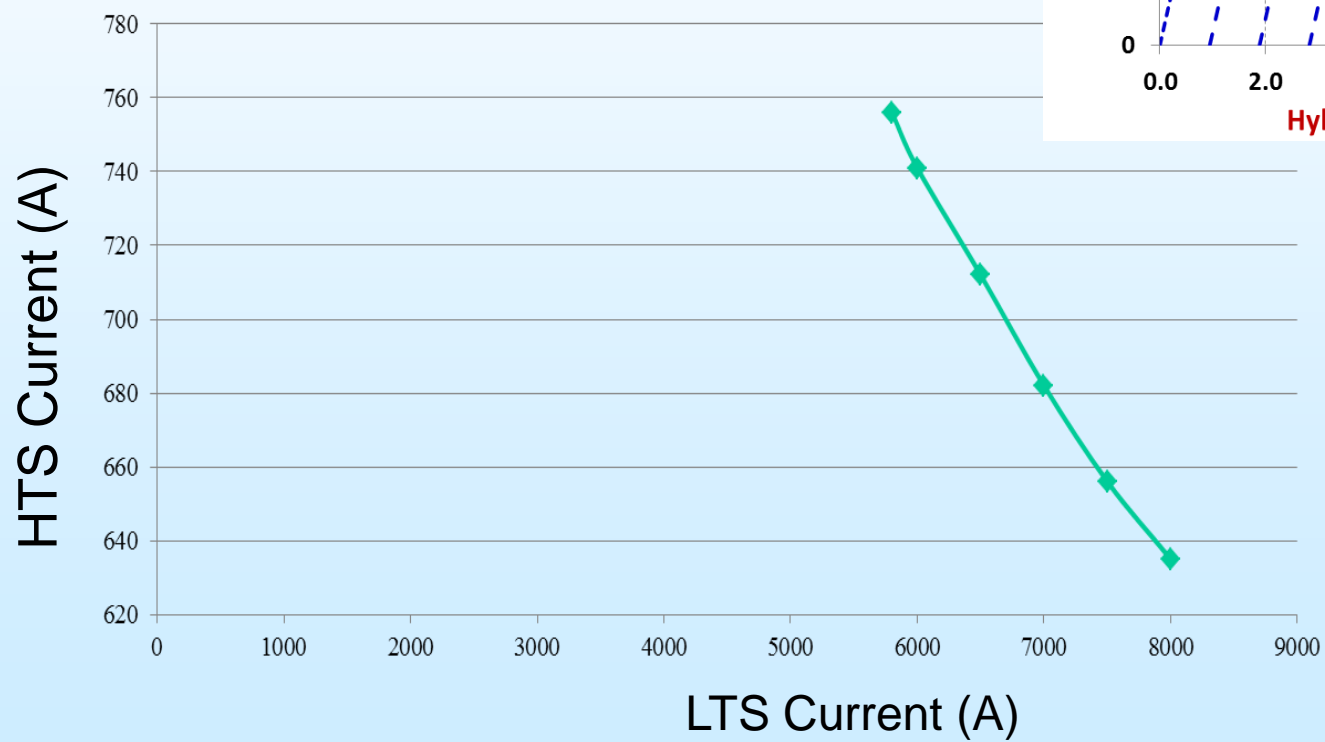
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Energy coupling during quench

LTS Current=6000A

HTS Current at quench=741A

LTS Common Coil Current (A)

HTS coupling

LTS coils should be operated with some margin below quench current

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LTS Current (A)	HTS Quench Current (A)
8000	635
7500	656
7000	682
6500	712
6000	741
5800	756

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Conclusions

- System performed as expected.

- Transient data gave very good insight on cross coupling of energy between HTS and LTS at quench.

- LTS has to be operated with some headroom in current.

- Established proven sequence of action to protect both coils irrespective of which quenches first.

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