TE-MPE-EE

Knud Dahlerup-Petersen - on behalf of the complete team.
IST (incl. short-circuit tests) & HwC of the 234 Energy Extraction Systems in the LHC:

- Started with re-writing of the relevant EDMS documents (the ‘procedures’) to cover all upgrades and experience gained since 2010.

- IST took place March – August 2014. Completed the week of HwC start-up.

- 5 teams (3 Polish, 2 Russian) of each 2 specialists + supervisor shared the task (covering 13 kA and 600A installations).

- Measurements at ultimate current was organized with the warm powering circuit in CLOSED CIRCUIT.

- Participation in the Heat Runs (by special team) where cables had been replaced (ΔU @ all conical connections (6µΩ) and across breakers (23µΩ), thermo-couple measurements, PICO).

- Special polarity tests added for checking of the polarities of the two release systems of the 13 kA breakers. Will be a part of the EDMS procedures.

- A final CHECK-LIST was established and added to the to-do list (but separate doc).

- NOTE: All stored-energy related IST tests must take place during HwC. Eg. PLI3.b1 & PNO.b1 of 600A systems and all measurements on the extraction resistors.
Development and use of an Automatic Test System for Commissioning of the 600 A Energy Extraction systems in the LHC corrector circuits

Purpose: To be able to perform the Hardware Commissioning steps PLI3.b1 (current distribution and total voltage drop measurement) and PNO.b1 (opening time measurements) WITHOUT human presence in LHC underground.

A set consists of two testers:
16 analogue channels per tester
Each channel can multiplex between 4 differential signals.
5 voltage pick-up points per EE system.

2 new tests are in production (Dec. 2014)

The two existing testers were successfully used for commissioning of sectors 67 and 12. Now being moved to sector 56.
After the breaker cleaning which precedes the measurements, no human presence in the tunnel is needed.
Reconstruction of the 1232 Local Protection Units for all LHC Main Dipoles:

**General:** Upgrade of the electrical systems, driven by the need to improve the quench heater supervision and diagnostics capabilities and to have a redundant powering scheme.

1. **Enhanced monitoring of DQHDS Heater Discharges:**
   - Voltage monitoring alone during discharges appears insufficient to track defects in Strip Heaters.
   - Pulse current precision measurements during discharges to be added.
   - Introduction of 5’000 Broadband Pulse Current Measurement Trfo’s.
   - Developed and produced in close collaboration between MPE-EE and a Polish trfo manufacturer.
   - Our AGH and HNINP engineers were deeply involved in this project.

2. **Powering of the QPS system in DYPB racks:**
   The iQPS systems never profited from the availability of the TWO independent UPS lines. The earlier used switched-mode, tri-volt power supplies had shown some weaknesses during re-starts.
   It was decided to launch the design and production of 2’700 new power supplies, each with 7 output voltages (floating and referenced to ground). Production-to-print, complete design made by MPE.

3. **New electrical shuffling crate – the DQLIM:**
   - For replacement of the so-called ‘Crawford box’, 1232 in total.
   - Each new crate shall house four pulse current transformers, two new power supplies, cable patches, voltage dividers etc. Assembled in Industry according to CERN drawings.
Other MPE-EE activities related to the ‘yellow rack’ upgrade - in pictures and numbers:

A huge logistics issue (with Bruno)

Search for and repair of Non-Conformities

The dream-team for DYPB assembly and functional testing (with EP and MS sections).

‘Tropicalization’ of the pcb’s for a number of DQLPR’s.

Cable recuperation and manufacture:
5000 power cables
5000 signal cables
42000 continuity tests
37000 HVQ tests

Photos courtesy of E. Nowak..
ELQA after SMACC

SMACC => created almost a new machine

So, all connections and instrumentation wires need to be checked carefully

- SMACC consolidation follow-up with LS1-PAQ tests
- Standard campaigns before powering tests
  - At warm and at cold
  - All circuits in the LHC to be checked
  - Instrumentation of all magnets to be checked
  - 76 NCs discovered (Nov. 2014)
  - Reference for QH discharge tests
  - Trends in capacitance of certain circuits
  - Updated HVQ procedure for RB circuits
- ELQA before and after CSCM
- Dipole diode lead measurements at warm
  - 39 NCs discovered
- Insulation monitoring during thermal cycles

Examples of applied bypasses: RCSA34B2 circuit.
Upgrade of Cold Diode Leads for LHC Main Dipoles

The general test set-up:

RESULTS:
The diode lead measurements include three bolted / clamped busbar connections: the half-moon, the busbar-to-heatsink and the heatsink-to-press pack.

Acceptance threshold: 15.5 µΩ max.
All 8 sectors were measured! A significant task!
Upgrade of Cold Diode Links for LHC Main Dipoles (contd.)

From all sectors (except S45) - before correction of outliers. (1858 leads). Sum of three contact resistances.

Non-Conformities were:
- Lead resistance (before correction) outside limit: 8 places (one as high as 210 microOhm/90 microOhm)
- Poor V-tap: 1 place
- Swapped V-taps: 8 places
- Swapped I and V-tap: 1 place

Courtesy: M. Bednarek
Completion of the Warm Busbar Measurements program
Preliminary results from the Dipole Circuit

Interconnecting busbar segment data from across sector 81, after compensation of the nQPS system loading. After LS1 upgrade.

Results of warm magnet resistance measurements across sector 81. After LS1 upgrade.

Board A: Busbar segments only

Board B: Busbar + diode branch

Results from the complete LHC dipole circuit, except S67, after LS1.

All results of busbar segment resistances vs. temperature.

Busbar segment normalized differential resistances – Board B (busbar + diode leads)

Busbar segment normalized differential resistances – Board A (no diode branches)

The measurement team (Bob & Sandor), missing: Bozhidar and Luke.
Development and use of an Automatic Test System for Commissioning of the 600 A Energy Extraction systems in the LHC corrector circuits

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Concept and design of a prototype 15 kA IGBT-based Monopolar Energy Extraction Switch for the 30 kA/10 kA Test Benches in SM18 - presently in development

Basic parameters and characteristics:

- Switch Opening Time < 1ms.
- 8 parallel branches, each rated 2 kA, 1500 V in two columns
- Individual IGBT’s, over-rated to minimize the forward voltage drop
- Laminated, water-cooled busbars for emitter / collector connections.
- IGBT heat sinks directly water-cooled
- Capacitors at each busbar level for inductance compensation.
- Triple, laminated, water-cooled central busbars
- Drivers: One master, three slaves per column.
- Shunt and LEM used in this prototype design.
- Fuse – for magnet protection in each branch (under study)
- Leak-free water connectors of type Parker

Detail: One IGBT branch with air-cooled flexible busbars connected to the two external central busbars, current measurements with shunt and LEM - under development.

Detail: IGBT, basic heatsink and emitter / collector LAMINATED BUSBARS with added-pipe cooling necessary for continuous DC operation.

Detail: Power connections at the top for 4 x 500 mm2 water-cooled cables
The IGBT switch for 15 kA commutation (contd.)

The circuit topology for up to 30 kA operation:

The low-induction concept of each ‘leg’:
Plug-in Module of a 1 kA, 1 kV IGBT-based Energy Extraction Switch as alternative to electro-mechanical breakers

Basic features:

- Rating: 1 kA, 1 kV max. - Two plug-in Modules needed for bipolar operation.
- Opening time: < 1 ms max.
- IGBT redundancy in both directions.
- Featuring power series-diode for increased reverse voltage withstand of up to 1 kV in both directions.
- ‘Multi-Contact’ lamella power connectors to a rack bus.
- Water-cooling of the IGBT’s. Natural-air cooling of all busbars.
- Extensive use of laminated busbar conductors.
- Capacitive compensation of parasitic inductance.

- Associated extraction resistor:
  - Natural-air cooled array of series/parallel connected carbon-disk resistor elements.
  - To be housed outside the switch inclosure.

Carbon-disk based DQR resistor/energy absorber of 1 MJ @ 1 kV.
Schematics of the 1 kA, 1 kV IGBT switch:
Considerations of max. $\text{He}_{\text{gas}}$ pressure during quenching lead to a demand for a total extraction resistance of $2.8 \, \Omega$, with energies not exceeding $2 \, \text{MJ}$. Such requirement, combined with the interest in using existing equipment, could be satisfied with a system design including two, identical, symmetrically placed LHC energy extraction facilities, rated $600\, \text{A}$, $450\, \text{V}$.

This topology has the further advantage that the power converter will remain at ground potential during energy extraction, provided that the system earth point is placed in the middle of the converter. New $1.4 \, \Omega$ energy absorption resistors are needed. The two systems per test bench (3 test benches total) will be located in a single rack, such as in the LHC corrector circuits. No water-cooling is required.