**ELQA contributions during 2015**

After the LHC machine closure following end of LS1 every s.c. circuit and every magnet instrumentation was tested at warm and cold by the combined CERN/HNINP (Cracow) team.

Last ELQA Standard test was performed on 11.02.2015.

16 non-conformities were discovered after the standard ELQA campaign:

<table>
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<tr>
<th>EDMS</th>
<th>Title</th>
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<tr>
<td>1469061</td>
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The investigation of non-conformities and the TS2/iDQQBS validation required 103 a HV additional qualification tests and 16 LV tests.

The upgrades applied to the LHC energy extraction systems during LS1 lead to a substantial reduction in the rate of failures, observed during the first year of operations.

The statistics of the MPE on-call team interventions provide the evidence:

- **13 kA systems (32):** 2 issues (one broken diode rectifier bridge and a short-circuit in DJRQD (Morosov cabinet, permanent FPA). Non of them affected the system protection.

- **600 A systems (202):** 13 issues (two closing failures, broken Traco pwrS, spurious opening, broken rectifier bridge, cold solder, holding coil rupture, two main axle ruptures). Only concern: last two events. Only the last subject may cause trouble (overheating) during operation.
QPS ‘Yellow rack’ upgrade

The substantial upgrade during LS1 of the local dipole quench protection racks (DYPB) provided immediate and continuous advantages during the 2015 LHC operation, resulting in an availability close to 100 %.

New linear power supplies with seven separate LV outputs, enhanced supervision of the heater discharges, a consolidation of the quench heater power sources and a new signal and power transmission unit have contributed to this improved performance.

An example of how the new monitoring of the discharge currents allowed an early intervention to change the heater configuration:

One of the 1232 new DQLIM crates of the ‘dipole yellow racks’ with its four precision measurement transformers for heater discharge current monitoring and slots for two of the new linear, regulated power supplies.

Defect heater #3 of dipole A26R8 shows up with footprint only in the current signal / invisible on the voltage picture. Heaters were reconfigured in time to avoid further energy dissipation which could lead to damage of the cold mass.
Further ELQA Activities: Collaboration with HNINP for upgrade of ELQA equipment and associated software

- Development of a new DAQ Interface and other upgrades of the High-Voltage Insulation Testers, with delivery of 10 complete systems (Addendum KE2570)
  - Improvements:
    - Galvanic insulation between HV crate and computer motherboard
    - Same output impedance for all measurement ranges
    - USB connections instead of RS232
    - New calibration feature on demand
    - HV withstand of all components brought to 3 kV
    - AC separation between the HV source and the circuit under test

- Development of new hardware for the Arc Interconnection Verifications (nAIV), with new central unit, for connection to a TP4 system (Addendum KE2571)
  - Improvements:
    - The hardware of the existing AIV testers for continuity and polarity checking of the spool-piece and N-line circuits is outdated, often failing and the codes are obsolete
    - There’s a wish to make a new test system compatible with the recent TP4 systems, for use in the shown setup with a central unit for signal dispatch and communication.
    - The contacts to the wires in the N-line box will be improved
    - The test routines will remain unchanged (EDMS 1269127)

- Development of new software tools for ELQA (Addendum KE2572)
  - Reasons:
    - The system hardware modifications required implementation of software changes
    - New 4-wire MIC measurement procedure
    - Merge of TP4 and DOC
    - Many suggestions from the users, based on operational experience

- Provision of assistance during TS’s and YETS’s until 2018, but not including LS2 – (Addendum KE2776)
  - Common CERN/HNINP teams have jointly worked on Consolidation Programs for CL Heater Systems, Non-Conformity Follow-ups, Earth-Fault Current Measurements and participation in the DQQBS Board Replacement Campaign.
New Component and System Developments #1

CLIQ Energy Exchanger Unit: Concept, design and manufacture of the First Industrial Version

- Current (purple) and voltages (red/green) during an energy exchange between CLIQ and a test inductor.
- Double (bi-directional) thyristor (2 in 1) with redundant firing pulse generation for reliable switching (500 ms application time), for currents up to 6000A.
- The two first units after successful testing on a LHC cryo dipole at cold, ready for packing and shipment to Fermilab.
- Regulated charger system for constant current (100 mA) charging to 500 V (in steps of 50 V) of the 40mF / 80mF dry thin-film capacitors.
Concept, design and prototyping of a 7.5 kA IGBT-based, monopolar switch – to be used as basic unit for a new generation of ultra-fast, high-current energy extraction systems

The Immediate Application: 2 x 2 such modules shall protect the magnets to be tested in the 30 kA bench of SM18/Cluster ‘D’ - then followed by similar modules for equipping 10 kA and 20 kA test facilities.

The challenge:
Unprecedented demand for a total release time below 2ms (including the commutation time) requires

- new technologies
- innovation
- INTEGRATION of experience gained by other teams
- application of solid electrical power engineering principles

Photo: First prototype ready for type testing in the new 15 kA test bench in B377.
The BASIC 7.5 kA module features:

- 4 selected IGBT’s (low $V_{CE}$) \( \sim 1850 \) A / branch

- Use of laminated busbars wherever possible

- Triplet main busbar configuration for residual stray field minimization and identical busbar impedance for each IGBT branch

- Forced - water cooling of IGBT Emitter & Collector terminals in addition to the IGBT heat sink cooling

- Distributed capacitance to compensate the parasitic inductance at three different levels of each IGBT branch

- IGBT gate driver configuration: one Master + three Slaves

- Controls and acquisition: cRIO (+ PXI during the test phase) - in addition to a completely CERN-designed new layer of protection electronics

- High reliability and robustness of both power part and controls

- The associated extraction resistor is composed of carbon disks.

The new 5 kA power test facility now completed inside the P-Hall extension, with a new 15 kA test bench for power testing of fast semiconductor switches.
One of the three central busbars (manufactured by ‘Hollmen’ Finland) after Ag coating. Only the middle busbar is directly water cooled.

The basic switch: High power density IGBT from ‘Infion’ with lowest possible $V_{CE}$.

Attempts to provide direct liquid cooling of the IGBT wafers are ongoing in EE lab. The IGBT cover is removed and the standard gel is not injected. The coolant is a fluorinated dielectric heat transfer liquid from 3M company.

Laminated busbars mounted on IGBT for 1875 A branch current. Busbar-mounted capacitors at level-2 shown.

Machine and stencil for precision application of thermal contact grease on IGBT heat sinks.
**New Component and System Developments #3**

Development and prototyping of a 1 kA mono- or bipolar, redundant semiconductor switch for energy extraction purposes

**Concept and design details:**
- Modular and compact design with use of ‘all-laminated’ busbars, combined with distributed capacitive compensation of stray inductances at three distinct levels, for suppression of voltage transients occurring during the commutation.
- Redundancy obtained through two series-connected IGBTs per polarity, with separate drivers.
- Plug-in concept: One module = monopolar switch, two modules = bipolar switch. Common control electronics in case of bipolar operation.
- Water cooling of IGBT heat sinks will be mandatory. The dimensions of the laminated busbars should allow air cooling only.
- The systems are being developed for a possible replacement of existing 600A EE facilities of the LHC corrector circuits, if required, as extraction switches for magnet test benches (with possible extension to 2 kA) and as extraction systems for the Hi-Lumi correctors.
New Component and System Developments #3 contd.
Collaboration agreement with IHEP/Kurchatov, Russia: Addendum P109/A11

Development and Production of New Tooling for Periodical Maintenance and Adjustments of the Main Energy Extraction Breakers – plus support by IHEP staff for the Breaker Maintenance Program during YETS

Signal transmission unit for collection, conversion and transmission of data simultaneously from all DQS switches of one LHC energy extraction facility to a laptop for storage and comparison. For use during the yearly maintenance campaign and in case of trouble during operation. The data logger will do the AD conversion and transmit the data to the PC.

Associated software will sort, compare and store the oscillograms in the data base.

Schematics of the circuitry and components for determination of intra-turn short-circuits by pulse application and response recognition. The 1900-turn ‘holding’ coils to be checked are inserted into a resonance circuit which is powered from the 300 V oscillator to be built at IHEP. The oscillation pattern depends on the number of turns in short-circuit.

S + development of digital force gauges for main and arc contacts
Cold By-pass Diodes for the LHC Main Circuits: Creation of new stacks for use in LS2 Replacement Magnets and as Spares

- Update and register the Autocad drawings for dipoles and quads, with all modifications applied during previous campaign.
- Create an updated list of all materials to be used, reference to European norms, grades and designations.
- Write new Technical Specification from latest FP Template, including all improvements applied during LS1 preparations.
- Split tendering into 1) electrical and mechanical elements and 2) insulating parts.
- Measure all available press-pack spare diodes at RT and 78 K: Electrical tests in forward and reverse direction and Fuji-paper footprints.
- Start the split tendering procedure. Evaluation, selection and order placement.
- Follow-up of the manufacture in Industry.
- Assembly of the stacks, HVQ and individual testing at RT and 78 K.
Other on-going projects:

- **Next generation of extraction resistor systems in the multi-MJ range:**
  - Immersed type for fast recovery time – cooling through liquid/water heat exchange
  - Immersion in dielectric, fluorinated fluid with high cooling capabilities and high boiling point
  - Modular design for external resistance changes
  - Compact design for minimizing space requirements

- **Next generation of CLIQ units:**
  - The EE order books include:
    - 3 units of a further experimental energy exchanger for SM18, featuring 10 different charging voltages and a new charger system
    - A first redundant system covering shorts and open circuits in the capacitor bank
    - Start of series production in Industry

- **Next generation of mechanical switches for Energy Extraction:**
  - Development of an ultra-fast vacuum breaker (few ms), in collaboration with Techn. Universities in Poland
  - Adaptation to our needs of state-of-the-art air breakers from European Industry – mainly for test benches

- **With MPE/EP and Industry:**
  - Development of $\text{d}l/\text{d}t$ sensor for quench-protection