AUTOMATIC ANALYSIS AT THE COMMISSIONING OF THE LHC SUPERCONDUCTING ELECTRICAL CIRCUITS

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INTRODUCTION

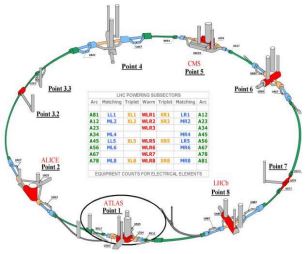
The first LHC Hardware Commissioning Campaign (HCC) was started early 2008. The aim of this crucial phase, mandatory before to put an accelerator into operation, was to test in real conditions all the equipment and systems of the machine. It included protection systems and all the superconducting electrical circuits. For this purpose, two types of tools were developed, one to manage the execution of the tests and a second to provide data analysis, to deal with the big amount data from the tests. The initial approach used when designing these analysis tools, was to help users to perform manual analysis of the data with a tool that permitted to select a test result set, automatically load interesting signals and display them in a GUI that could easily be used by experts from several domains.
During the HCC, human and time resources have been optimized. Less people were available for the LHC start-up tests therefore to speed up the tests, the framework and the applications have been improved to permit execution of tests in parallel on several circuits. Furthermore, with the increased electrical circuits knowledge, it has been possible to set limits to measured and calculated parameters, which lead to automate part of the analysis.

THE ELECTRICAL CIRCUITS AND THE LAYOUT OF THE LHC

More than 8000 superconducting and 100 warm magnets are installed in the LHC accelerator. They are powered in more than 1600 electrical circuits, with currents ranging from 60 A (for small orbit corrector magnets) up to 13 kA for the main bending dipoles and focusing quadrupoles.

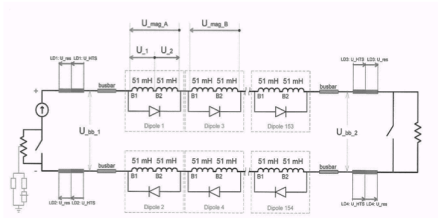
	S12	S23	S34	S45	S56	S67	S78	S81
13kA	3	3	3	3	3	3	3	3
IPD	3	2	2	3	1	0	2	3
IPQ	14	7	6	13	12	5	7	14
600AEE	23	27	28	24	23	27	27	23
600AAcb	14	20	20	14	14	20	20	14
600AnoEE	16	9	2	9	9	2	9	16
120A	50	37	22	33	33	22	37	50
60A	94	94	94	94	94	94	94	94
TOTAL	217	199	177	193	189	173	199	217

Repartition of the circuit types over the 8 sectors.



The LHC electrical circuits are split into 8 independent sectors, that are subdivided into 35 powering sub-sectors, of 4 different types.
- 8 for powering the magnets in the arc cryostats.
- 8 for powering of the Inner triplet cryostats.
- 12 for powering the smaller cryostats in the matching sections.
- 7 for powering of normal conducting magnets left and right of an IP.

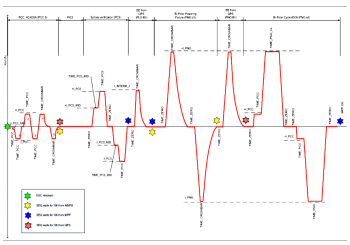
In most circuits, the stored magnetic energy is sufficient to destroy magnets and bus-bars. Protection of the equipment relies on the fast detection of resistive voltages, on a bypass of the current around the quenching parts, and on fast and reliable extraction of as much energy as possible.



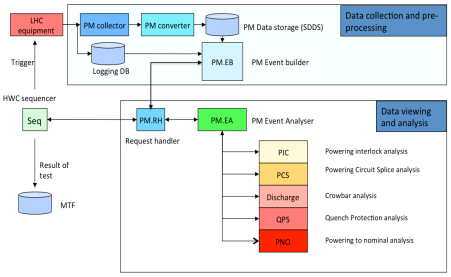
Simplified view of an electrical circuit for dipole magnets.

OVERVIEW OF THE ELECTRICAL CIRCUIT COMMISSIONING

The Electrical Circuit Commissioning (ECC) consists in validating the individual reactions and the correct communication between the Quench Protection System, the Power Converters and the Powering Interlock System. Different current cycles are applied on these circuits to validate them, up to nominal current.

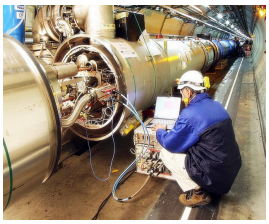


Current cycles for 600 A circuit validation.



The test framework is made of 3 main systems. The **Sequencer** application allows edition of test cycles and then execution of command toward the power converters. The **Post Mortem Request Handler** collects the files generated by the equipment after the test and associates them to the test parameters. Then the **Post Mortem Event Analyser** provides a GUI to experts, to easily retrieve and analyse a test. Several **Analysis Panels** have been built, dedicated to viewing executed current cycle and values returned by the involved equipment.

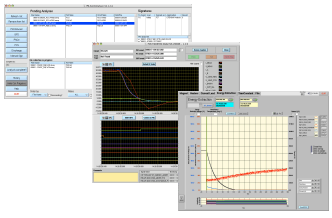
To validate a **test step**, the event generated must be analysed and **signed by experts** of all involved domains (interlock system, powering, quench protection, cryo). When they all have signed and accepted the analysis results, this information is returned to the Sequencer. This allows either to launch the next test step, or when the full sequence have been performed and accepted, to validate the electrical circuit. In case of rejection of one analysis, the test sequence is blocked. The problem then, must be investigated and solved. This could needs a tunnel intervention to make some measurements on site or to replace some parts in case of a device failure.



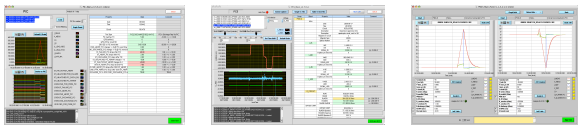
High voltage qualification in the LHC tunnel.

FROM MANUAL ANALYSIS TOWARD FULLY AUTOMATED TESTS ACCEPTANCE

The first LHC Hardware Commissioning Campaign in 2008 was a complete machine commissioning. So **15532 tests** were executed, for 12666 successful, during 164 days. Some analysis tools have been specifically developed, to help experts, in validating the test results.

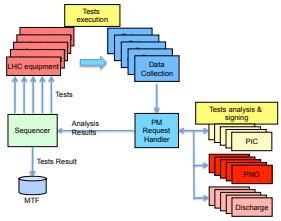


Analysis tools developed for the first LHC HWC.



To overcome the problem of the number of tests to be signed by the experts, it was decided to automate some analysis. This was made possible from the ECC 2009, by the knowledge acquired from the previous campaign. The first tool fitted with **automated analysis** was the Powering Interlock Controller (**PIC**). Initially through this application the expert verified some patterns and the synchronization of signals, according to various parameters, like circuit type, test type and protection equipment present in the interlock loop. After one complete ECC, expected delays and synchronization scenarios were well known. They have been easily coded as LabVIEW™ VI and introduced as new algorithms. The **PNO** and **DISCHARGE** tools then have been automated. We have added summarized tables, with measured and expected criteria. Overranged values are highlighted in red. A button allows expert to sign the test (accept or reject) after an authentication procedure.

A new step in improving the efficiency of ECC has been reached with the **automated execution and signing** of the analysis. This concept has been developed and used at the beginning of 2011, during the last ECC.



The automated framework used during ECC 2011.

FACTS AND DIFFICULTIES

Hardware Commissioning Campaigns
- HCC 2008: 15532 tests in 164 days.
- HCC 2009-2010: 13611 tests in 89 days.
- Analysis tools developed to help experts.

Human and organisational aspects
- ECC improved with execution of tests in parallel since 2009.
- Some campaigns needed working in 3 shifts by day.
- Too many tests to check according to the available experts.
- Analysis results are coarser after the 200th due to users weariness.
- Each rejected test required particular attention to fix the non-conformity.
- Experts who sign the tests are also those needed for tunnel interventions

Electrical Circuit Commissioning
- ECC 2009: Introducing automated analysis for some of the tests.
- ECC 2011: 6092 tests in 21 days, 3204 automated signing.
- Knowledge increased about expected results, so lot of criteria and acceptance limits have been defined.
- Automated tools regularly validated with known results from reference tests.
- Time gained with automated signing liberates experts for other tasks.

CONCLUSION

The Electrical Circuit Commissioning of the LHC is now a well-defined and documented exercise fitted with powerful procedures and software. The automated analysis and results signing have proven their utility and efficiency. Reducing the time devoted to this task, helped to reorganize the experts' responsibilities and to decrease the number of people implicated. Most of the electrical circuits have been qualified to 3.5 TeV operation. During the 2013 long shutdown, their qualification to 7 TeV will require extended sequence of tests. Fully automated test framework will be a key point for an efficient ECC execution.

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