THE POST-MORTEM ANALYSIS SOFTWARE USED FOR THE ELECTRICAL CIRCUIT COMMISSIONING OF THE LHC

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Abstract

The hardware commissioning of the LHC has started in the first quarter of 2007, with the sector 7-8. A suite of software tools has been developed to help the experts with the access, visualization and analysis of the result of the tests. Using the experience obtained during this phase and the needs to improve the parallelism and the automation of the electrical circuits commissioning, a new user interface has been defined to have an overview of all pending tests and centralize the access to the different analysis tools. This new structure has been intensely used on sector 4-5 and during this time the test procedures for different types of electrical circuits have been verified, which has also allowed the implementation of new rules and features in the associated software. The hardware commissioning of the electrical circuits enters in a more critical phase in 2008, were the number of the tests executed increases rapidly as test will be performed in parallel on different sectors. This paper presents an overview on the post mortem analysis software, from its beginning as a simple graphical interface to the actual suite of integrated analysis tools.

INTRODUCTION

The operation of the Large Hadron Collider relies on many systems with state of the art technologies in many fields and in particular several thousand superconducting magnets operating in superfluid Helium at 1.9 K powered by more than 1700 power converters. A sophisticated magnet protection system is crucial to detect a quench and safely extract the energy stored in the circuits after a resistive transition.

In order to ensure safe operation, all this equipment has to be tested, first at the manufacturers, then at CERN under true operating conditions before installation into the tunnel and finally commissioned after installation. This applies to the power converter systems (from 60 A to 12 kA), the superconducting magnets and elements (current leads, bus-bars...), and also to the protection systems, such as the quench protection, the energy extraction system and the related interlocks.

The last part of the Hardware Commissioning is the Electrical Circuit Commissioning where each circuit is being driven through a series of tests to provoke all interlock and safety systems' reactions and validate the circuit for nominal current in all aspects.

To help the equipment experts and accelerator operators to access and analyse the data generated during these tests, a set of event reconstruction and analysis tools has been developed [1].

Using our experience as measurement and analysis systems developers, based on LabVIEW programming and industrial components, we have elaborated a modular design and a staged approach for the implementation of these tools. This solution has proven to be a good compromise between development cycle time, maintainability and expandability [2].

SYSTEM OVERVIEW

A wide range of the LHC systems (power converters, machine protection systems, beam monitors...) have been designed to acquire their most important parameters in circular buffers, with the aim to process them "Post Mortem" in case of a fault [3]. At the reception of a Post Mortem trigger, these buffers are frozen and transmitted to the Post Mortem system for storage and analysis [4,5,6]. During the Electrical Circuit Commissioning, several systems interact together when combined for powering and protecting a superconducting circuit.

The Post Mortem system has two main parts, the server and the client, and is surrounded by the sequencer and the databases (Fig.1). The sequencer application controls the power converters, which execute a ramp or current cycle. The controllers of the equipment send the Post Mortem data at the arrival of a trigger and the Post Mortem system collects the buffers from all systems. The Post Mortem Request Handler combines the Post Mortem data with the test performed by the sequencer and the Post Mortem Event Analyser (PMEA) collects all such events for presentation to the equipment experts for analysis. This application allows the experts to execute different analysis programs and data viewers that enable them to verify the success of the test and to use an electronic signature to pass or fail it. The PMEA keeps track whether all signatures needed have been obtained, which in turn allows the next step to be executed or not.

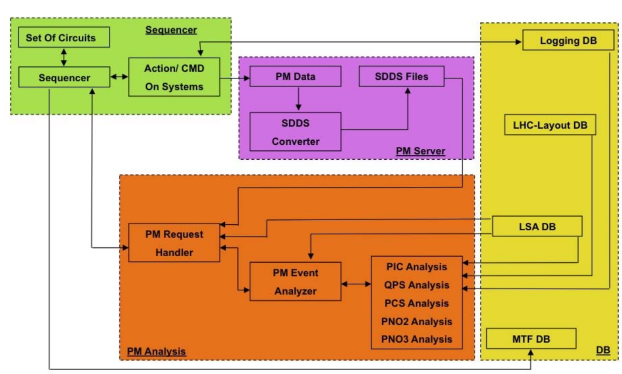

Figure 1: Post Mortem System Layout.

Depending on the test, up to four different expert domains have to inspect and validate the results. The final result is being sent to the sequencer for upload into the MTF (Magnet Test Folder) database, and either to accept the test, to repeat it or to open a procedure for non-conformity. In the first case, the next commissioning steps will be executed on the circuit. In the last, the circuit will be blocked, until the problem is corrected or a decision is taken to perform a new test with modified settings.

MODULAR DEVELOPMENT

At the design of the Post Mortem system, we had identified four basic functions, which gave us a modularity that allowed parallel development of the components. These functions were the PM data collector, the data converter, the data browser and the data analysers. They are in a logical dataflow sequence and were the first to be developed. The Post Mortem Browser was the first tool in the form of a data viewer, which could list data by date, by equipment type and location, load the data for graphing or display in a table and then apply a basic set of functions to the data, such as scaling, zooming, and derivative and FFT calculation. The Post Mortem browser has been intensively used during the early stages of the LHC HWC, devoted to the individual equipment tests. It became clear, however, that with the increase in the number of tests on one sector and with sectors commissioned in parallel, we had to add one higher level of data handling. This level should group data depending on the tests initiated by the Sequencer and led to two more functions: the Request Handler, to receive the Sequencer requests and group the data for the test and the Event Analyser, to present the grouped data as one event and giving access to analysis programs on this data set.

POST MORTEM EVENT ANALYSIS

The PM Event Analysis has been designed to follow through the different analysis steps and keep track which expert approves and which one fails the test. The analysis applications started from the PMEA will automatically load the data as grouped by the Request Handler. The expert is guided by the PMEA to analyse the data with the appropriate tool, but remains free to choose the tool he/she wants for further investigation. Also, experts with different roles can use different analysis tools on the same data set. We have defined five roles of experts and depending on the test either one needs to sign or maximum up to four. The roles and signatures have been implemented using the Role Based Access Control (RBAC) system, initially foreseen only for protecting equipment access. The functionality of the RBAC system, however, was equally well suited for the approval of tests by different experts, avoiding errors. Five specific analysis applications have been developed and linked to the PMEA: for interlocks, power converters, quench protection and two for magnet powering. Furthermore, two more analysis applications have been developed, for cryogenics and the distribution feed boxes, but are not yet linked into the approval chain. The PM Browser is the tool that allows free browsing and viewing. Each specific analysis application automatically checks a number of parameters between limits or shows the modelled circuit behaviour in overlay with the measured data for the experts to compare and conclude. None of the applications take automatic decisions, but show in red or green colour the results, according to pre-defined criteria, to focus the expert's attention to a possible problem. It is always the expert's decision to pass or fail a test.

PMA DETECTED NON-CONFORMITIES

Several problems have been detected through one of the analysis programs of the PMA suite.
Most non-conformities, such as broken voltage taps, shorts to ground, etc., are detected during the Electrical Quality Assurance phase that is executed just before the ECC.

As examples of problems found during the ECC, we can point out: inverted instrumentation signals on the QPS, inversion of current lead measurement on the power converters, inverted interlock signals, but also tests that do not reveal the expected reaction or data.

One of the case studies is related to the energy extraction system. It has been designed to extract most of the stored magnetic energy upon a quench of a superconducting magnet chain. If the extraction system is too slow to react for any reason, the current bypass diode could be damaged. Repair of such a diode requires a warm up to ambient temperature of the magnet before the repair can take place and successive cool down, which means many weeks of downtime for the LHC. With this in mind, the energy extraction system has been designed to respond as quickly as possible. During the ECC of sector 4-5, the main quadrupole extraction system was tested at low current.

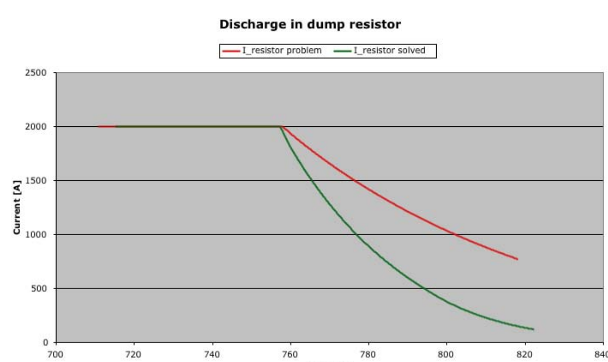

Figure 2. Dump resistor discharge problem

At first, everything seemed to have functioned qualitatively as it should. But after careful quantitative examination of the data using the PM browser, it became clear that one of the systems wasn't acting fast enough. The time constant was significantly longer than it should be (Fig.2). Following a deeper investigation, a major internal short was discovered in the dump resistor and the whole assembly was replaced. Later, one found out that the problem was caused by damage during transport combined with a lack of appropriate quality assurance at the end of the production.

CONCLUSIONS

The Post Mortem analysis is an essential set of tools, not only for the commissioning of the LHC super-conducting circuits, but also for a reliable and safe operation of the LHC. During commissioning it has proven to shorten significantly the time to qualify a superconducting circuit and for the LHC operation it is foreseen to shorten the downtime after an event that stops the beam. The modularity of the software architecture has allowed the first set of tools to be used during the commissioning of the LHC and will permit the re-use and extension of these tools for the LHC beam commissioning and operation.

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