QPS UPGRADE AND MACHINE PROTECTION DURING LS1

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Abstract

The presentation will explain all the proposed changes and discuss the impact on other shutdown activities.
The upgrade of the LHC Quench Protection System QPS during LS1 with respect to radiation to electronics will concern the re-location of equipment and installation of new radiation tolerant hardware. The midterm plan for further R2E upgrades will be addressed.
The protection systems for insertion region magnets and inner triplets will be equipped with a dedicated bus-bar splice supervision including some additional modifications in order to improve the EMC immunity.
The extension of the supervision capabilities of the QPS will concern the quench heater circuits, the earth voltage feelers and some tools to ease the system maintenance. The protection of the undulators will be revised in order to allow more transparent operation.
The installation of snubber capacitors and arc chambers for the main quad circuits will complete the upgrade of the energy extraction systems.
Finally the re-commissioning of the protection systems prior to the powering tests will be addressed.

INTRODUCTION

The protection of the superconducting circuits of the LHC, i.e. magnets, bus-bars and current leads is ensured by electronic quench detection systems in combination with other active protection elements such as quench heater discharge power supplies and energy extraction systems [1] [2]. Due to the size and the location of these systems major upgrades can only be smoothly implemented during long shutdowns.

The refurbished and upgraded systems are expected to run without major overhaul at least for 3 to 4 years, i.e. until the next long shutdown.

The LHC run after the first long shutdown LS1does not require any principal changes of the protection functionality; some protection settings however need to be adapted to the higher beam energy.

Based on the experience during LHC operation so far, several requests for enhanced supervision and diagnostic capabilities of the protection systems have been issued by equipment owners, experts and users. These requests concern the LHC operation as well as the hardware commissioning campaigns.

In addition there will be some upgrades improving the maintainability of the protection systems, such as enhanced remote control options and a new generation of software tools for automatic analysis and configuration of device parameters.

R2E RELATED ACTIVITIES

Relocation of QPS equipment

The QPS will profit from the occasion to relocate certain protection systems from radiation exposed to low radiation areas. This activity [3] concerns the inner triplet protection systems installed in UJ14, UJ16 and UJ56 and will basically require the displacement of two racks per area and the installation of new instrumentation cables.

With respect to the necessary replacement of the obsolete and not fully radiation tolerant field-bus coupler chip type MicroFip™ the infrastructure of the QPS field-bus networks will be modified for the deployment of the new NanoFip^{CERN} based DAQ systems. Hereby the number of segments will be doubled increasing as well the data transmission capabilities of the fieldbus networks.

Radiation tolerant hardware

The deployment of radiation tolerant hardware for quench detection systems starts already in 2012 and is basically required for systems installed in the exposed underground areas RR13,17, 53, 57, 73, 77, where a re-location of QPS equipment is not possible during LS1.

In addition some potentially vulnerable systems (e.g. splice protection systems) installed in exposed areas of the LHC tunnel will be upgraded.

Figure 1: Radiation tolerant quench detection board for insertion region magnets and inner triplets

EQUIPMENT UPGRADE FOR INSERTION REGION MAGNETS & INNER TRIPLETS

Bus-bar splice supervision

The protection systems for the insertion region magnets and inner triplets will be equipped with a dedicated bus-bar splice supervision allowing permanent monitoring equivalent to the systems already in use for the LHC main circuits. Due to the fast discharge time of these circuits the splices are very well protected by the global protection system. Therefore it is not necessary to connect the bus-bar splice supervision to the powering interlocks.

The upgrade requires the installation of 102 new protection crates. The currently installed crates, detection and DAQ systems can be re-used after being refurbished. The capabilities of the DAQ systems will be enhanced including the means for advanced quench heater diagnostics (see below).

Enhanced EMC immunity

In order to transmit the additional signals for the splice supervision and to reduce at the same time the risk of false triggers of the protection systems caused by electrical perturbations, the instrumentation cables and the proximity equipment installed close to the DFB need as well to be modified and require a re-cabling campaign.

ENHANCED DIAGNOSTICS FOR QUENCH HEATER CIRCUITS AND UPGRADE OF THE MAIN DIPOLE PROTECTION SYSTEMS

Motivation for enhanced diagnostics of quench heater circuits

The upgrade is driven by the intention to reduce the risk of damage to the quench heater circuits of the LHC superconducting magnets, especially the main dipoles and insertion region magnets [4]. The present system monitoring only the discharge voltage is not sensitive enough to detect all fault states of the quench heater circuits, specifically failures of the heater strips.

All of the few quench heater faults observed so far during LHC operation could be mitigated by disabling the respective heater circuit and switching to a low field heater.

There is however a risk of quench heater related faults, e.g. a short to coil compromising the electrical integrity of the magnet, requiring at least an exchange of the magnet. As a first measure to minimize the risk of such failure the test discharge voltage has been reduced to ~10% of its nominal value of U_{HDS} = 900 V by implementing a dedicated test mode. For LHC exploitation after LS1 and the preceding commissioning campaign the risk will slightly increase, basically due to the magnet training campaign [5].

The enhanced quench heater supervision is supposed to identify clearly a faulty quench heater circuit and to reveal eventual precursor states of a potential failure.

R&D campaign in 2011

In 2011 a research and development campaign has been conducted evaluating several potential extensions of the existing DAQ systems with respect to improved quench heater supervision.

In particular two methods have been subject to study, the simultaneous measurement of the discharge voltage and current at higher sampling rates than used in the present system (20 kHz instead of 200 Hz) and the high precision ($\Delta R \approx 100\ \mu\Omega$) measurement of the resistance of the quench heater strip. The first method will require the installation of additional current transformers adapted to the discharge current of the quench heater power supplies; the second a precision automatic measurement system integrated into protection crate. This instrument will remain disabled and disconnected from the heater circuits while magnets are powered.

Both methods will deliver significantly more information about the state of a quench heater strip but will require a substantial upgrade of the currently installed protection systems.

Protection crate upgrade

The implementation of these extensions requires the construction of new protection crates, as the presently installed ones cannot house additional measurement systems. The existing quench detection electronics and DAQ systems however can be re-used. The new crates will contain as well spare slots for eventual further extensions.

Adaption to redundant UPS powering

The new protection crates will be as well adapted to profit fully from the redundant UPS powering scheme implemented in 2009. In addition the state of the two redundant power sources will be permanently monitored by the built-in DAQ systems.

EARTH VOLTAGE FEELERS

The earth voltage feelers will monitor the electrical insulation strength of the LHC main circuits especially during fast discharges. The system will as well measure the electrical insulation strength between adjacent bus-bars. As all acquired data will be stored in the LHC logging database, the evolution in time can be studied easily. In case of an eventual earth fault the system will allow to identify rapidly the location of the fault position on the half-cell level. This will significantly reduce the occupation time in the LHC tunnel of the teams in charge of the precise localisation and repair.

Per sector a maximum of 54 devices for the main dipole circuit and 55 for each of the main quad circuits can be installed (1308 units in total). The installation and commissioning will be staged starting in 2012 with one sector and being completed during LS1.

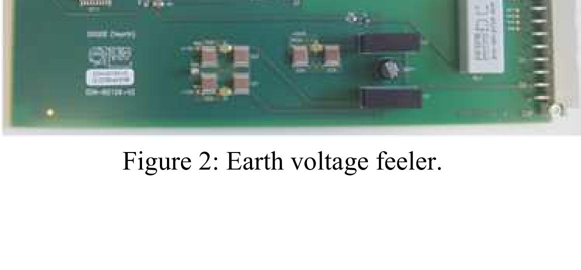

Figure 2: Earth voltage feeler.

GENERAL SYSTEM OPTIMIZATION

During LS1 a number of system upgrades will be implemented with the aim of improving the availability of the data from the redundant electronic channels and the system maintainability.

This concerns for example the full visibility of all redundant circuit boards in all layers of the QPS supervision including post mortem data. This change requires a modification of the QPS firmware and will result in an about a factor three increased data flow to the logging database. At the same time the post mortem data volume will be doubled.

The protection systems for the two undulators will be revised in order to allow more transparent operation. Hereby the automatic enabling of inductive compensation should allow higher ramp rates and operation without re-calibration in between technical stops.

The quench loop controllers supervising the QPS internal interlock loops for the LHC main circuits will be equipped with redundant current sources for the loops and dedicated measurement boards for enhanced diagnostics especially with respect to false triggers including the interface to the powering interlock controller.

Enhanced remote control

The remote power cycle feature, currently available for the 600 A protection system and the nQPS part of the main circuits, will be extended to the majority of the DAQ systems. This is as well a prerequisite for the envisaged firmware download via the QPS supervision.

All newly developed circuit boards allow the remote control of a wide selection of device parameters. During LS1 it is planned to link this feature to a dedicated QPS configuration database allowing the automatic configuration of a system after an intervention.

UPGRADE AND MAINTENANCE OF THE ENERGY EXTRACTION SYSTEMS

13 kA energy extraction systems

During LS1 the installation of new arc chambers for the RQD / RQF extraction switches needs to be completed in order to increase the maximum operational voltage of these circuits. This will allow to keep the discharge time constant of the RQD / RQF circuits short ($\tau < 20$ s).

At the same time the installation of the snubber capacitor banks in the RQF/RQD circuits (16 installations in total) will be executed.

Figure 3: Snubber capacitor bank for a RQD / RQF energy extraction system (photo courtesy K. Dahlerup-Petersen).

600 A energy extraction systems

The 600 A energy extraction systems will be submitted to a general upgrade campaign focussing on an improved fixation of the holding coils and an additional supervision of the internal current distribution. All 48 extraction resistors will be upgraded resistors for accepting double energy deposit.

RE-COMMISSIONING OF THE PROTECTION SYSTEMS

All the work performed during LS1 will require a full re-commissioning of all protection systems prior to the powering tests. This activity comprises the complete electrical quality assurance for all superconducting circuits, the test of all QPS instrumentation cables and the quench heater circuit qualification prior to the implementation of the enhanced supervision layer.

These tests will be succeeded by complete individual system tests checking the hard and software interlocks as well performing the quench heater discharge tests. The system tests will be completed by a thorough verification of the QPS supervision.

The re-commissioning campaign will profit from the experience gained so far but will remain challenging. Additional tests will be required during the powering tests in order to qualify some newly installed items like the upgrades of the energy extraction systems and the earth voltage feelers.

SUMMARY

During LS1 the LHC quench protection and energy extraction systems will undergo substantial upgrades basically focussing on enhanced diagnostic capabilities and improved system maintainability. Table 1 lists the basic hardware changes, which will be complemented by the respective firmware and software upgrades.

Table 1: Foreseen upgrades of the QPS during LS1

Item	**Quantity**
Protection crate main dipoles	1232
Protection crate inner triplets	8
Protection crate insertion region magnets	94
Rack powering and interface module	418
Bus-bar splice supervision system	360
Radiation tolerant fast digital quench detection systems	632
Measurement boards	2268

REFERENCES

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