Changes in QPS

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Abstract

During the upcoming first long shutdown (LS1) of the Large Hadron Collider LHC, the protection system for the superconducting elements of the LHC (QPS) [1] will be substantially upgraded with the principal objectives to extend its diagnostic capabilities and to enhance the system immunity to ionizing radiation. All proposed measures will serve as well to optimize the overall system dependability. The supervision of the quench heater circuits of the LHC main dipoles will be enhanced by adding additional measurement channels for the discharge current and by increasing the sampling frequency and resolution of the related data acquisition systems. By this measure it will be possible to identify potential fault states of the quench heater circuits, which may affect the integrity of the concerned magnet. At this occasion all main dipole protection systems will be submitted to general overhaul after four years of successful exploitation. The consolidation measures for the protection systems within the radiation to electronics project will be concluded by installing the latest versions of radiation tolerant quench detection systems. In addition some equipment will be relocated to shielded areas. All LHC main circuits will be equipped with earth voltage feelers allowing the monitoring of the electrical insulation strength of the LHC main circuits especially during fast discharges.

INTRODUCTION

The QPS of the LHC covers 544 superconducting circuits with nominal current ratings from 550 A to 11870 A. The systems incorporate a large number of individual protection and data acquisition devices requiring very high levels of reliability and availability. Due to the complexity of the QPS, major upgrades can only be implemented smoothly during long shutdowns. The refurbished and upgraded systems should then be able to run without major overhaul for at least for 3 to 4 years. The LHC operation after LS1 does not require principal changes of the protection functionality but a few quench detection settings have to be adapted to the higher energy of the accelerator. Within the preparation of LS1 several requests to enhance the supervision and diagnostic capabilities of the QPS systems have been submitted by equipment owners, experts and users. These changes are regarded necessary for the LHC exploitation as well as for the preceding hardware commissioning phase. Apart from the advanced supervision capabilities, other features will be implemented with the objective to ease maintenance and exploitation of the protection systems. These improvements comprise enhanced remote control options, automatic analysis and maintenance tools, and the implementation of a system configuration database.

RADIATION TO ELECTRONICS CONSOLIDATION

Within the radiation to electronics (R2E) project [2] several upgrades for the QPS electronics aiming to improve the immunity to ionizing radiation will be performed during LS1.

Relocation of equipment

An important part of the consolidation work consists in the relocation of QPS equipment presently installed in underground areas UJ14, UJ16 and UJ56. This equipment is used for the protection of the inner triplet low beta quadrupoles and the corresponding corrector magnets, and accounts for 12 out of 35 beam dumps caused by the QPS due to radiation induced faults in 2012.

Deployment of radiation tolerant hardware

The consolidation will be completed with the deployment of radiation tolerant hardware for the protection of the insertion region magnets and the 600 A corrector magnet circuits. These protection systems are currently installed in underground areas RR13, RR17, RR53, RR57, RR73 and RR77 and cannot be relocated during LS1. While the newly developed radiation tolerant quench detection sys-tems for the insertion region magnets (see figure 1) have been already fully validated and produced, the development of the more sophisticated systems for the 600 A corrector magnet circuit protection still needs to be concluded. The upgrade of these systems is absolutely mandatory as other-wise the rate of spurious system triggers after LS1 is likely to reach a level being no longer acceptable for LHC oper-ation. As complementary measures enhanced power-cycle options for DAQ systems including automatic re-start of stalled field-bus couplers will be implemented. This serves as an intermediate solution until new DAQ systems based on the radiation tolerant NanoFip [3] field-bus coupler chip are available.

ENHANCED QUENCH HEATER SUPERVISION

The upgrade of the quench heater circuit supervision of the LHC main dipole (MB) protection systems is driven by the intention to reduce the risk of damage to the quench heater circuits. The present system, monitoring only the

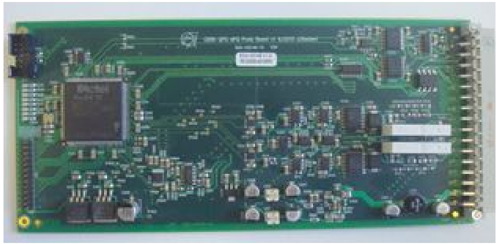

Figure 1: Radiation tolerant, FPGA based quench detection board type DQQDI used for the protection of insertion region magnets.

discharge voltage, is not sensitive enough to detect all fault states of the quench heater circuits, especially 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 one of the spare heaters located in the low field region of the magnet. There is, however, a non-negligible risk of a quench heater fault provoking a short to the magnet coil or compromise the electrical integrity of the magnet. The enhanced quench heater supervision is therefore supposed to reveal precursor states of such potential failures. The newly developed system (see figure 2) records simultaneously the discharge voltage and current using sampling rates up to 192 kHz and 16 Bit resolution analog to digital converters (ADC). In addition there is a special operational mode to verify the state of internal fuse of the quench heater power supply. This fuse is part of the grounding path of the internal capacitor bank and protects the power supply in case of a quench heater isolation fault. Up to now its state can only verified by manual inspection of the quench heater power supply. The full exploitation of the capabilities of the new systems requires as well the development of sophisticated high level software tools for the detailed analysis of the collected data. The present protection crates cannot be extended to house the additional measurement systems. It is therefore necessary to install newly developed protection crates; the existing quench detection electronics and DAQ systems however, can be re-used. The protection racks type DYPB housing the protection crates and the quench heater power supplies need as well to be refurbished completely.

Figure 2: Dedicated DAQ board type DQHSU for the supervision of quench heater circuits.

Adaptation to redundant 230 V UPS powering

The new protection crate is adapted to the redundant 230 V UPS powering scheme introduced for QPS systems in 2009 [4]. Each crate will be fed by two external radiation tolerant AC/DC LDO converters. For the LHC main circuits RB and RQD/RQF the protection systems must remain active also during fast discharges of the superconducting circuits, e.g. in case of a electrical power cut. The redundant powering of the quench detection systems is therefore of particular importance for the main dipole circuits of the LHC, which have a nominal discharge time constant of $\tau = 103$ s.

Organization of protection rack upgrade work

Due to the significant number of modifications necessary to implement the enhanced quench heater supervision, it has been decided to perform this work outside the LHC in a dedicated assembly and test area. This simplifies also the testing of the upgraded systems after completion of the upgrade work. It requires, however, the transport of 1232 protection racks (160 tons of material, figure 3) from the LHC to the assembly area and back.

Figure 3: Protection rack type DYPB installed underneath the main dipoles.

EARTH VOLTAGE FEELERS FOR THE LHC MAIN CIRCUITS

The earth voltage feelers will monitor the electrical insulation strength of the LHC main circuits especially during fast discharges. The system (see figure 4) will as well measure the electrical insulation strength between adjacent bus-bars. As all data will be stored in the LHC logging database also the evolution in time can be studied. In case of an eventual earth fault the system will allow to identify the location of the fault position on the half-cell level. Per sector 54 devices for the main dipole circuit and 55 for each of the main quad circuits will be installed (1312 units in total).

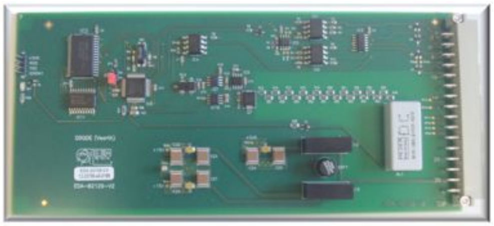

Figure 4: Earth voltage feeler type DQQDE.

GENERAL SYSTEM REVISION

The QPS systems have been exploited since 2007 and the respective hardware designs and firmware developments are dating back to the year 2002.

Hardware

Besides the extension for the supervision and protection of the bus-bar splices and the aperture symmetric quench detection implemented in 2009 (nQPS layer) [4], no major hardware change of the QPS systems has taken place so far. During LS1 some meanwhile obsolete systems will be replaced by new developments offering improved or enhanced functionality. In particular this concerns the quench detection electronics for the insertion region magnets and inner triplets as well as the systems for the 600 A corrector magnet circuits being exposed to ionizing radiation. The routing of the warm instrumentation cables for the protection of magnets Q9 and Q10 will be revised to achieve better immunity against electrical perturbations, especially during power outages and storms. At this occasion also a non-conformity in QPS / DFB instrumentation interface will be fixed. Apart from the mandatory upgrades, there are a number of optional but wishful improvements, such as the implementation of a hardware multi-trigger option for the DAQ systems and a revision of the quench loop (inter-lock) controllers focusing on the redundancy of loop cur-rent sources and enhanced diagnostics.

Energy extraction systems

The installation of arc chambers for the 13 kA energy extraction switches of the RQD and RQF circuits has to be completed in order to increase the maximum operational voltage of these circuits. This will allow to keep the discharge time constant of these circuits at $\tau < 20$ s. At the same time the installation of the snubber capacitor banks for the energy extraction systems of the RQF and RQD circuits will be executed [5]. All the 600 A energy extraction systems will subjected to a general upgrade, including an improved fixation of the holding coils and supervision of the internal current distribution [6].

Firmware

All detection system firmware will be reviewed with the objective to fix some vulnerabilities revealed during the last years and to identify possible other. This includes also an improved protection against non-conform user manipulations. The revised firmware is compatible with remote access to specified device parameters, thus allowing automatic crosschecks with configuration databases. The firmware of the QPS data acquisition systems will be adapted to to the increased resolution and higher sampling rates of analog signals. The QPS device firmware updates are relatively tedious as it concerns many circuit boards with only the last generation being fully adapted to automatic download.

QPS supervision

The transmission capacity of the physical layer of the QPS field-bus will be significantly improved by doubling the number of segments thus reducing the number of field-bus clients per segment. The reduced number of clients allows to shorten the macro-cycle length of the bus arbiter from 200 ms to 100 ms resulting in a maximum data update rate of 10 samples per second. The transmission of the QPS data to the LHC logging database will be improved and the filtering of analog data discarded. This will ease the data analysis and automatic checks of the system integrity. The full exploitation of all QPS upgrades presented so far requires a series of new high level supervision tools, *e.g.* for the enhanced quench heater supervision data analysis and for fully automatic signal integrity checks. Finally the QPS configuration database needs to be commissioned as well during LS1. With the help of this database all essential device parameters can be verified by software and the download of some parameters, e.g. the nQPS compensation coefficients, can be performed automatically. Critical parameters of course can only be manually set by experts.

Quench detection parameters

The quench detection parameters, especially for the 600 A corrector magnet circuits, have been carefully revised by quench calculation experts [7]. Their results show that some of the very conservative settings can be relaxed without compromising the integrity and performance of the protected elements. This will increases the QPS system dependability significantly, ease its exploitation and reduce the LHC machine downtime. It is noteworthy that longer evaluation times and higher threshold voltages may reduce the complexity of the detection electronics, which is especially beneficial for the development of radiation tolerant systems [8].

RECOMMISSIONING AND OPERATION AFTER LS1

All the work performed during LS1 by will require a full re-commissioning of the quench protection systems prior to the powering tests. The commissioning phase will be preceded by the complete electrical quality assurance for all superconducting circuits including the test of all QPS instrumentation cables. The individual system tests of the QPS comprise the validation of all (13722) hardware interlock channels, quench heater discharge tests, qualification of energy extraction systems, verification of data transmission to QPS supervision and the check of software interlocks. The re-commissioning activities will profit from the experience gained so far [9] but will remain as usual challenging. Additional tests will be required during the powering tests in order to qualify some newly installed items. The QPS system exploitation will change significantly after LS1 and some teething problems are expected during the initial exploitation phase. Due to the higher LHC energy the turn around time after trips will be significantly longer (about a factor 1.5); at the same time more real triggers, *i.e.* beam induced quenches are likely to occur. It is also noteworthy that after LS1 almost all superconducting circuits will operate outside their self-protecting range.

Operational support by service teams

Efficient training of service teams (MPE stand-by service, MP3, MPE-coms) will be essential to get all members familiar with the upgraded systems. In addition it is very likely that the scope and membership of the various service teams will change after LS1. In general and after an initial LHC operation phase less but more complex interventions of the stand-by service are expected; this will require a substantial training effort.

SUMMARY

The upgrade of the QPS systems during LS1 aims to increase the system dependability and to enhance its diagnostic capabilities. A successful upgrade will reduce the LHC machine downtime significantly, especially due to the reduced number of radiation induced trips. The newly installed systems allow by far more preemptive fault diagnostics and improve the maintainability, *e.g.* by adding more remote control options. The planned modification and enhancements of the QPS represent a major upgrade only feasible during a long shutdown period and requires a substantial effort. To make this work a success sufficient time for testing and re-commissioning including some contingency has to be allocated.

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