ENHANCED QPS – PERFORMANCE, COMMISSIONING AT 3.5 TEV, OUTLOOK TOWARDS 5 TEV

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Abstract

During the shutdown of the LHC in 2009 the protection system for superconducting elements in the LHC QPS has been submitted to a substantial upgrade.

The newly introduced layers of the QPS allow the monitoring and protection of the electrical interconnections between superconducting magnets with very high precision and extend the capability of the system to the timely detection of so-called aperture symmetric quenches in the LHC main magnets.

In addition the immunity of the QPS with respect to powering failures has been improved by feeding all quench heater based protection systems by now two fully redundant UPS.

FUNCTIONALITY OF THE ENHANCED QPS

The upgrade of the QPS in 2009 extended the functionality of the existing system by adding a dedicated system for the protection of the electrical interconnections between superconducting magnets as well as for the detection of so-called aperture symmetric quenches in the LHC main magnets [1].

Splice Protection System

The splice protection system type DQQBS permanently monitors and interlocks the voltage across the interconnections between LHC main magnets.

The determination of the required detection threshold is based on simulations and tests [2] and has been set to U_{TH} = 300 μV with10 s evaluation time at nominal current I = 12 kA. For operation up to 3.5 TeV, i.e. currents up to I = 6 kA a threshold voltage of U_{TH} = 500 μV with 10 s evaluation time is regarded as sufficient.

Apart from the interlock functionality the new system provides data for the enhanced diagnostics of the superconducting circuits via the QPS supervision.

Dedicated powering cycles the so-called “Mexican pyramids” allow the measurement of the splice resistance with a resolution of $\Delta R < 1n\Omega$. The evaluation of data recorded during coasting can be used to trace the development of splice resistances in time.

Symmetric Quench Detection System

The symmetric quench detection system type DQQDS extends the functionality of the existing protection system in order to detect timely aperture symmetric quenches. The design detection threshold is U_{TH} = 200 mV with 20 ms evaluation time.

The new system detects also “normal” quenches and serves as a back-up of the existing system. This feature has been used for the implementation of the now fully redundant UPS 230 V AC powering scheme including power supplies and electrical distribution lines.

The symmetric quench detection system will become essential for the training of the superconducting magnets up to nominal current, where a significant amount of aperture symmetric quenches due to quench propagation after the occurrence of a primary training quench is expected.

COMMISSIONING OF THE ENHANCED QPS

Up to currents I = 2 kA, where the circuit protection is fully ensured by the standard QPS, the enhanced QPS can be commissioned and qualified in passive mode e.g. not connected to interlocks and quench heaters. The commissioning comprises the verification of signal integrity and completeness, tracing of wiring errors, assessment of noise levels and the adjustment of device parameters such as threshold and filter settings.

Commissioning of the Splice Protection System

The splice protection system needs to compensate the apparent inductive voltage across a bus-bar splice during a ramp; the corresponding compensation coefficients have to be deduced from data acquired during current ramps up to I = 2 kA.

A first bus-bar splice mapping during commissioning allows the identification of potential problems at moderate currents.

Commissioning of the Symmetric Quench Detection System

The symmetric quench detection system is based on a multichannel evaluation logic supervising three magnets.

In LHC due to the relatively long discharge time constants of the main circuits the system has to be active in all phases of a powering cycle. The selected detection scheme ensures a very reliable detection of quenches but it is potentially vulnerable to false triggers especially during fast current discharges of the circuit. In order to avoid such triggers adaptive filters, which are only active during the transition from ramping or coasting to current discharge are implemented in the numerical detection algorithm. The proper setting of these filters has to be verified during the commissioning.

In addition snubber capacitors for the energy extraction systems will be needed for LHC operation at energies higher than 3.5 TeV [3].

The check of the immunity of the symmetric quench detection with respect to fast discharges is a mandatory test to be repeated each time the energy is increased.

Activation of interlocks and final verification

Once successfully commissioned up to I = 2 kA the new system has to be connected to the interlock chain and the link of the symmetric quench detection system to the quench heater circuits of the protected magnets be enabled. As a final verification step current ramps up to I = 2 kA have to be performed before using the by then fully operational system at higher currents.

For the final commissioning up to 3.5 TeV the false trigger immunity of the symmetric quench detection systems during activation of the energy extraction has carefully to be checked at I = 4000 A and I = 6000 A. The splice mapping has to be performed at I = 5000 A profiting from the improved signal to noise ratio at higher currents.

PERFORMANCE OF THE ENHANCED QPS

Splice mapping and inductive compensation

Fig. 1 shows the results of splice mapping up to I = 2 kA in the dipole circuit of sector 7-8. The measurement is conducted fully automatically and is combined with the internal splice mapping of the superconducting magnets using the so-called snapshot method developed for the existing QPS. One splice mapping campaign, which can be conducted simultaneously for the three main circuits of a sector, takes about 3 hours.

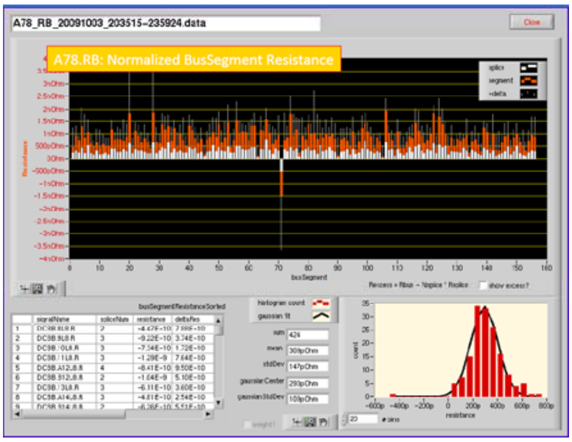

Figure 1: Splice resistance measurement in sector 7-8.

The compensation of the apparent inductive voltage across a bus-bar splice has been successfully tested and a procedure for the determination of coefficients and download to the protection device developed. An example of a run with a fully compensated system is shown in Fig. 2.

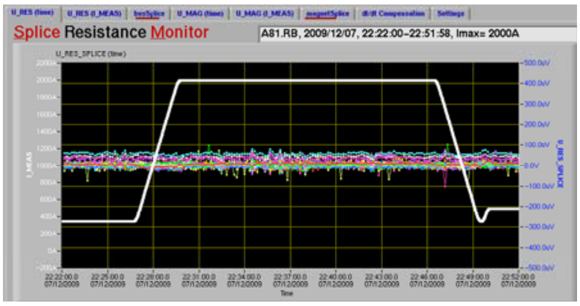

Figure 2: Resistive voltage during ramp and coasting after fine tuning of the inductive compensation values in sector 8-1.

Symmetric quench detection

One of the challenges of commissioning of the symmetric quench detection system is to ensure its immunity to false triggers during fast current discharges. Fig. 3 shows the recording of the diagnostic buffer of a symmetric quench detection board during such a discharge. Without the use of adaptive filters the system would have triggered

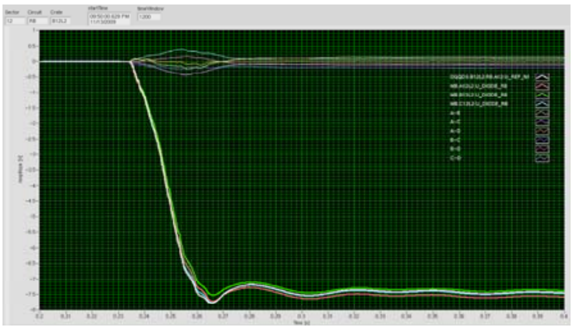

Figure 3: Activation of energy extraction systems at I = 4 kA in sector 1-2 and data recorded by a symmetric quench detection board (dump of diagnostic buffer).

Experience in sector 1-2 during the 2009 run

Sector 1-2 has been the only sector during the 2009 run with the enhanced QPS being fully activated and interlocked. The new system, which is adding about 500 hardwired interlock channels per sector (total number will increase from 7700 to 11500), showed a good stability during LHC operation with beam and apart from the transfer line magnets no interference by other LHC equipment (BLM's, kicker magnets …) has been observed.

The crosstalk from the LHC beam transfer lines is giving problems to a limited number of splice protection systems to operate with a threshold voltage of

U_{TH} = 300 μV. The threshold for the 2010 run being set to U_{TH} = 500 μV solves temporarily the problem until a long term solution becomes available.

The new system has been fully integrated into the QPS supervision requiring a substantial effort by the controls groups to handle the significantly increased data flow.

In addition dedicated tools for the data analysis like the splice resistance monitor [4] have been successfully validated; the development of specialist tools for device diagnostics and maintenance has been started and will continue.

FURTHER DEVELOPMENT OF THE ENHANCED QPS

Extension to insertion region magnets

An extension of enhanced QPS covering the insertion region magnets and the inner triplets will be ready for installation during the next shutdown. The necessary additional signal cables have been already installed in the LHC tunnel. These upgrades serve basically diagnostic purposes as the concerned circuits are already now fully protected by the present system [5].

Radiation tolerance

Several radiation test campaigns have been conducted throughout the year 2009 (at PSI and CNGS) confirming the design approach of the enhanced QPS. A potential problem is however related to the radiation weakness of the latest version of field-bus chip used in all QPS systems. Affecting only supervision and not protection a reliable replacement is nevertheless required. Until a more radiation tolerant version of this chip is available [6] a temporary workaround verified within the CNGS test campaign can be applied to affected QPS circuit boards.

SUMMARY

The commissioning of the enhanced QPS in 2009 resulted in the complete mapping of the interconnection splices in the LHC main circuits for the first time.

The design of the enhanced QPS has been successfully validated and theexploitation of the system during the LHC run in 2009 did not reveal any showstoppers so far.

The re-cabling campaign has been successfully completed end January 2010 and the electrical tests performed afterwards have been successfully concluded.

At the time of writing the full commissioning of the enhanced QPS up to 3.5 TeV is being completed and no major commissioning steps will be required for LHC operation at higher beam energies.

The main constraint with respect to the overall dependability (= reliability + availability + safety) of the QPS system is the large equipment number.

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