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LHC Project Report 1133

REVIEW OF THE INITIAL PHASES OF THE LHC POWER CONVERTER COMMISSIONING

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Abstract

The LHC requires more than 1700 power converter systems that supply between 60A and 13kA of precisely regulated current to the superconducting magnets. For the first time at CERN these converters have been installed underground in close proximity to many other accelerator systems. In addition to the power converters themselves, many utilities such as air and water cooling, electrical power, communication networks and magnet safety systems needed to be installed and commissioned as a single system. Due to the complexity of installing and commissioning such a large infrastructure, with inevitable interaction between the different systems, a three phase test strategy was developed. The first phase comprised the manufacture, integration and reception tests of all converter sub-systems necessary for powering. The second phase covered the commissioning of all the power converters installed in their final environment with the utilities. The third phase will add the superconducting magnets and will not be covered by this paper. The planning and execution that have led to the successful completion of these initial phases are described. Results and conclusions of the testing are presented.

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LHC POWER CONVERTERS

More than 1700 power converters [1] feed the different magnet circuits of the LHC. The systems are rated for between 60 A and 13kA, with a precision better than 50 ppm (of the nominal current) for the orbit corrector circuits and 3 ppm for the main circuits (main dipole, main quadrupole) respectively. For the first time at CERN, the majority of the power converters for an accelerator use high frequency switch mode (SM) technology. The exceptions are the main bend and warm magnet circuits where, due to the high power requirements, line commutated Thyristor technology (SCR) is used. The table below describes the circuits, indicating the quantity and location of the converters (U = underground, S = surface).

The requirement for so many power converters to be installed underground, and the high precision required of their output currents, necessitated a new test strategy for the LHC. The strategy revolves around three phases: the first phase relates to testing equipments on the surface; the second is dedicated to the power converter tests in the tunnel; the last phase concerns the final tests of the power converters with the magnets. Only the two first phases are described in this paper.

Table 1: LHC Power Converter types

PC type	Qty	Switch Type	½ hour stability	Area
MB [13kA/±190V]	8	SCR	3 ppm	U
MQ [13kA/18V]	16	SM	3 ppm	U
Inner Triplet [5..7kA/8V]	16	SM	5 ppm	U
IPD and IPQ [4..6kA/8V]	174	SM	5 ppm	U
600A type 1 [±0.6kA/±10V]	400	SM	10 ppm	U
600A type 2 [±0.6kA/±40V]	37	SM	10 ppm	U
120A [±120A/±10V]	290	SM	50 ppm	U
Orbit correctors [±60A/±8V]	752	SM	50 ppm	U
Warm magnets [1kA/450..950V]	16	SCR	20 ppm	S

PHASE 1

Development and Manufacture

Early in the LHC power converter development, it became apparent that it was necessary to split the converters into three sub systems to be able to achieve the precision demanded by the accelerator:

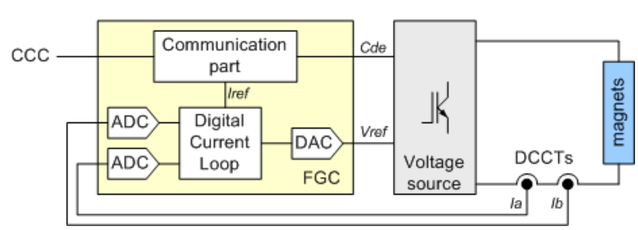

Figure 1: LHC power converter

1. Voltage Source (VS): This first sub system includes all the power components of the converter and its voltage control loop. Its development and production have been mostly carried out by industry throughout the CERN member states.
2. The DC Current Transducers (DCCTs): They measure with high precision the output current of the power converter. Their development and production, carried out in close collaboration between CERN and industry, have required special attention from CERN, because they largely determine the precision of the power converter.

3. Function Generation Controller (FGC): this part of the power converter includes communication with the CERN control room (CCC) and the digital current loop control with its ADCs and DAC. Its development has been fully realized at CERN and its production has been carried out by industrial partners in CERN member states.

Integration and Reception Tests

The reception tests comprised of two main stages of testing. The first stage tested the individual sub-systems of the power converter to ensure that it fulfilled the technical specifications required for the LHC. Once each element was fully tested and compliant, the process of integration by CERN could begin in order to obtain a LHC power converter.

Once the integration is completed, the power converter must be tested as a whole. In addition to the tests normally carried out on all power converters delivered to CERN (verification of the global performance, of the output voltage ripple, etc…), particular attention has been given to verify the precision of the current delivered by the power converter. For the first time at CERN, the accuracy of each power converter (half hour stability, reproducibility, linearity, etc…) has been systematically tested to assure the required performance is achieved on an inductive load..

Table 2: Summary of precision measurements made during the reception tests.

	13kA	4-7kA	600A	120A	60A
1	1.5±0.9	2.3±1.3	1.7±0.7	4.5±2.0	8.2±3.2
2	0.4±0.5	0.5±0.3	0.5±0.3	0.8±0.4	3.3±1.5

1: Stab@I_n, 2:Reproducibility

Test Results

To ensure the compatibility of the power converters with the other LHC electronic systems (quench detectors, cryogenic instrumentation, etc…), and also the precision of the converter output current, stringent EMC standards have been imposed on the output of the power converters. One of the objectives of the reception tests was to verify the conformity of power converters with these standards.

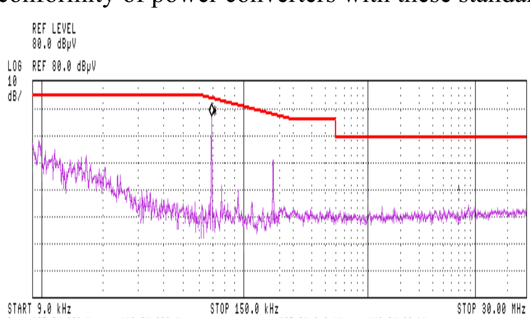

Figure 2: EMC measurements of an LHC power converter.

Phase1 Observations

The systematic verification of the power converter precision has allowed the early identification of a temperature variation issue at the level of the high precision ADCs [2]. Action was taken to improve the ventilation of all systems, and in addition a temperature compensation algorithm was implemented in the FGC. These modifications have been made prior to the installation of the power converters in the tunnel and their commissioning with the magnets.

PHASE 2

Short Circuit Tests

With the experience of the LHC String-2 testing, and the complexity of commissioning a large superconducting magnet installation, CERN decided very early in the program of LHC hardware commissioning [3] to introduce an additional phase of tests between the tests of the equipments on the surface and the final commissioning of the superconducting magnets underground. These tests [4], [5] had the objective of validating the warm elements of the power circuits (AC distribution, power converters, DC cables, etc…) and their associated systems (water cooling and air conditioning systems, WorldFIP communication networks, etc…). This was done with the conditions as similar as possible to those of final LHC operation. During these tests, the superconducting magnets were replaced by short circuits.

The LHC is composed of 24 independent power zones, two at each of the eight machine points and one in each of the eight sectors. As such, short circuit tests could be conducted in zones where installation was completed, in parallel with the delivery and installation of the power converters in other zones. Once the installation of a power zone was finished, short circuit tests were immediately realized. This strategy allowed the first powering tests in the tunnel to be made very early during the construction schedule, and to apply any modifications based on this experience to the subsequent systems still being manufactured and installed.

For the power converters, the short circuit tests consisted of:

1) Individually commissioning each power converter in order to ensure normal operation once installed. During this phase the interfaces with other systems of the accelerator (Power Interlock Controller, water cooling system, WorldFIP network, etc…) were tested.

2) Remote control from the CCC (CERN Control Center). This phase verified that each converter was correctly identified by the software application of the CCC and allowed many software applications to be tested that are necessary to remotely operate the power converters.

3) A 24hr heat run to validate and verify the influence of the power converters on the AC network of the machine and to demonstrate the good cooling of the

power zone and of the power converters, in conditions similar to nominal LHC operation at 7 Tev.

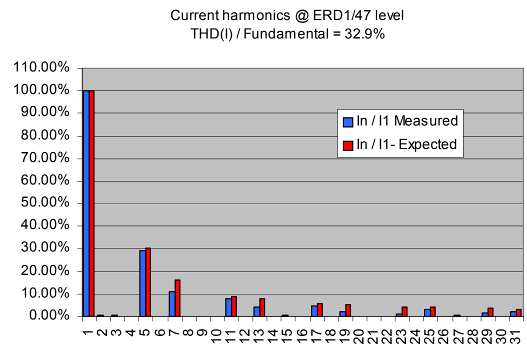

Figure 3: Harmonics on the power converter AC network measured during a 24hr heatrun.

Short Circuit Test Results

The majority of the LHC power converters are switch mode power converters with an output power less than 300 kW, and as such their input power stages are composed of diode rectifier bridges powered from a 3-phase 400V AC network. Harmonic currents generated by each power converter add together and give high global harmonic currents on the electrical network. In order to properly feed the power converters from the 18 kV machine network, special 18 kV / 400 V transformers that are capable of supporting this high harmonic level are used. The short circuits tests provided the opportunity to measure the harmonic level generated by the power converters and to validate the special transformer design before normal operation begins.

To obtain an accuracy of a few ppm on the current delivered by the main power converters (MB, MQ and Inner Triplet circuits), the ADCs and DCCTs of these systems have been installed inside air conditioned racks to ensure constant operation temperature. During the 24 hours heat run test, the design of these air conditioned racks have been validated and their constant internal temperature have been verified, particularly for a varying ambient temperature.

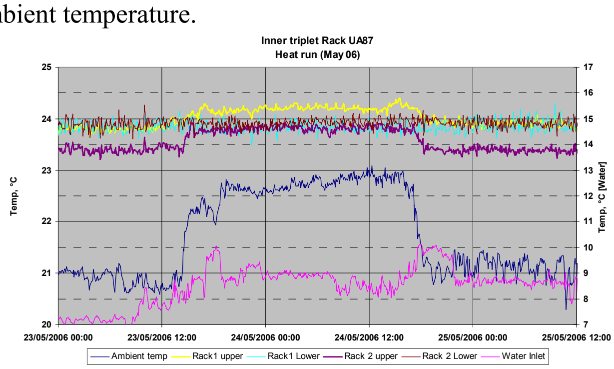

Figure 4: Internal temperatures of the air conditioned racks.

Phase2 Observations

Although all power converters destined for CERN accelerators are tested before their installation, design issues linked with their machine integration are often found during the final commissioning of the accelerator. During the LHC commissioning, several problems have also been encountered; however the short circuit tests have permitted the issues to be identified early in the power converter production cycle. The most important of these issues could be corrected before the hardware commissioning of the superconducting circuits begins.

CONCLUSION

The LHC is composed of 8 independent sectors and 24 separate zones from the point of view of the power converters. In this case, it was possible to develop a strategy to carry out the production, installation and commissioning in parallel. The advantages of this strategy reduced the time between the delivery of the power converters at CERN and the end of their installation. In addition, integration and installation issues could be identified early in the power converter production, allowing them to be corrected quickly to avoid costly modification campaigns once the power converters are installed. Further, the large scale validation of the power converter system could be made before the beginning of the hardware commissioning of the superconducting magnets, greatly facilitating this final phase of testing that is complex and, as we know by experience, sometimes painful. The short circuit tests also allowed a continual improvement of the converter software, and the validation of the software tools needed to remotely control the power converters, before the hardware commissioning of LHC began with the superconducting systems.

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