SYSTEMS OVERVIEW: POWER CONVERTER AND THEIR CONTROLS

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Abstract

In this paper, performance of power converters for the Run 2 of the Large Hadron Collider (LHC) is evaluated. This contribution focuses on the availability of different families of power converters, their evolution, analyses known failure modes and discusses mitigation of failures in the future. The last section describes new deployments and consolidation during the Long Shutdown 2 (LS2) and their impact on hardware commissioning for the Run 3.

POST-LS1 RECOMMISSIONING

During the LS1, multiple consolidation works were performed to improve the availability of the power converters for the Run 2.

A big part of this consolidation was linked to the Radiation-2-Electronics (R2E) project. First, certain converters were relocated to the zones with lower exposure to radiation, i.e. form UJs to UL14/16, UL557 and TZ76. Second, in the RRs in Points 1, 5 and 7, shielding was enhanced to decrease radiation levels. Finally, power MOSFETs were consolidated on all 400 Auxiliary AC-DC power supplies on 600A converters to avoid radiation damage due to Single Event Burnout. At the same time, a certain consolidation work took place on IDP/IPQ and RQD/RQF power converters in which the output module diodes were changed to more reliable ones as well as thermal environment of the converter was improved to further increase reliability. In the LHC60A converters, aging capacitors were changed in the auxiliary power supplies to improve its performance.

The impact on Hardware Commissioning (HWC) was moderate, all changes were validated in the EPC test zone A7 before being installed in the machine. In the locations where water-cooled DC cables were changed, short circuit tests were performed by short-circuiting the DC cables at the DFB and testing converter performance, full warm part of the cabling and ventilation. No major issues were experienced during the HWC.

POWER CONVERTER AVAILABILITY

Performance Overview During Run 2

Table 1 shows the LHC power converter types in operation during the Run 2 with their main characteristics, location and quantity. Fig. 1 shows the comparison of the root cause duration from 2015 to 2018. All faults reported in this plot are taken form the AFT tool. Power converter faults as well as total duration are stable and equal to around 100 faults and 100h of downtime. From 2017, an increased number of radiation related problems is observed due to increasing radiation levels in the RR locations mostly in point 1 and 5. In 2017, one long intervention on leaking water-cooled bus bars took place and lasted above 20h. Table 2 shows the evolution of availability of the LHC power converters during the Run 2 as reported in the TE-EPC piquet intervention database. The presented faults impact the machine availability. Radiation-induced faults in the power converter power and controls parts are counted separately. Data in this table partially come from [1-4].

RPMBx - LHC600A

The LHC600A are the least reliable LHC power converters and account for around 50% of total interventions. Number of interventions is stable around 50 per year. All the radiation-induced failures took place in RR locations on both controls and power part. 120 converters are installed in these locations , i.e. 30% of total population of RRs. All these units will be changed during the LS2 to the R2E-LHC600A converters controlled with the FGClite to eliminate the downtime due to radiation as well as some additional problems due to 0V-crossing and other known reliability failure modes. The rest of 280 units are installed in UJ/UAs with two dominating failure modes due to 0V-crossing and operational amplifier problems. The analysis of 2018 data is still ongoing and a consolidation to improve these two failure modes will be decided soon.

RPHx – LHC4-6-8kA

The LHC4-6-kA converters work reliably with a total number of failures below 10 per year on a population of 189 converters. Rare failures due to radiation have been recorded in the past and will be eliminated in the RRs thanks to the deployment of the new R2E-LHC4-6-8kA converter and the FGClite.

RPLB – LHC120A

Like in the case of the LHC4-6-8kA, the LHC120A power converters work very reliably as well with a total number of failures below 10 per year on a population of 290 units. No action is required to improve their reliability for the Run 3. In RRs, the controls will be changed to the FGClite to avoid future radiation related trips.

RPLA - LHC60A

The LHC60A power converter is extremely reliable with and average number of faults below 10 per year on a population of 752 units. During EYETS'16-17, the controls of these converters was fully migrated to the FGClite which was a first phase of deployment of the new controls in the LHC. Since the new deployment, no radiation related problems were observed and no FGClite hardware problems have been reported on any of the 752 installed units. Nevertheless,

Table 1: Main characteristics of the LHC power converters.

Typical use	Type	Current	Voltage	Location	Quantity
Main Dipoles	RPTE	13kA	180V	UA	8
Main Quads	RPHE	13kA	18V	UA	16
IPD, IPQ, IT	RPHx	4-6-8kA	8V	RR, UA/UJ	189
600A Multipole correctors	RPMBx	600A	10V	RR/UL, UA/UJ	400
Orbit correctors	RPLB	120A	10V	RR/UL, UA/UJ	290
Orbit correctors	RPLA	60A	8V	ARC	752
Saturn_2s	RPADO	850A	700V	SR	4
RPMC 600A-40V	RPMB	600A	40V	UJ/TZ	37
Other warm circuits	RPTx			UA/UJ/TZ	26
Σ					1722

Table 2: Evolution of availability of the LHC power converters during the Run 2 of the LHC as reported in the TE-EPC piquet intervention database and affecting the machine availability. The interventions performed in the shadow of other are not analyzed.

	2015		2016		2017		2018	
Converter type	Faults	R2E Power/controls	Faults	R2E Power/controls	Faults	R2E Power/controls	Faults	R2E Power/controls
RPMBx - LHC600A	38	- / 1	45	4 / 3	44	3/2	43	6 / 2
RPHx - IPD, IPQ, IT	12	- / -	10	1 / 1	6	-/ -	8	- / -
RPLB - LHC120A	15	2 / 1	9	- / 1	8	- / 5	8	- / 3
RPLA - LHC60A	5	- / 5	4	- / -	10	- / -	2	-/ -
RPTE - Main Dipole	-		3		7 (26h)		4 (3h)	
Saturn_2s					3		2	
RPMC 600A-40V	4		4		3		-	
Other warm circuits	~10		2		2		13	
Σ	**84**	**10**	**77**	**10**	**83**	**10**	**81**	**11**

the software integration has proven to be challenging in the first weeks post-deployment.

Other Power Converters

On the main dipole power converters RPTE, the main contributor to the fault time in 2017 was a leak on the water-cooled bus bars of the RB.A12 power converter [4], which required three interventions and a total of 26h to be fixed. A poor quality welding was observed on all power converters but did not contribute to a significant downtime in 2018 (3h). A consolidation of all bus bars will be done during the LS2. Saturn power converters were deployed during YETS'16-17 and help to significantly reduce the FMCM trips as shown in Table 2. On ALICE compensators, aging problems are manifested on capacitors due to over temperature. This failure mode will be addressed during the LS2. On other warm thyristor-based circuits, i.e. RPTM and RPTF, in 2018 an increase of number of trips was observed but analysis is not conclusive yet. If the failure modes can be identified and reproduced, they will be addressed during the LS2.

LS2 ACTIVITIES

Deployment of new equipment in the RRs

The main work will be done in the RR locations in points 1, 5 and 7. All the LHC600A converters in these locations will be removed and new racks with R2E-LHC600A power modules and the FGClite controls will be installed. The LHC4-6-8kA power modules will be removed and will be replaced with the new R2E LHC4-6-8kA modules. The controls of the LHC120A will change from the FGC2 to the FGClite. Consolidation of failure modes is planned on the other of 280 LHC600A in UJ/UA locations, changing the water-cooled bus bard on the main dipole RPTE converters as well as on ALICE compensators to improve problems with ageing capacitors.

Impact on Recommissioning

All new power modules to be installed will be tested in the EPC test zone A7 before being installed in the LHC. Power converter tests, with new controls and software are scheduled to be performed in the MPE testbed in building 272 to validate machine protection mechanisms as well as the software integration with the LHC HWC commissioning software (AccTesting). In RRs in point 1 and point 5, new water-cooled DC cables will be installed and will require new campaign of the short-circuit tests before the HWC campaign starts. During the HWC campaign, EPC requested 1-2 weeks of the expert tests to arrive to optimum performance of power converters and optimization of different current regulation

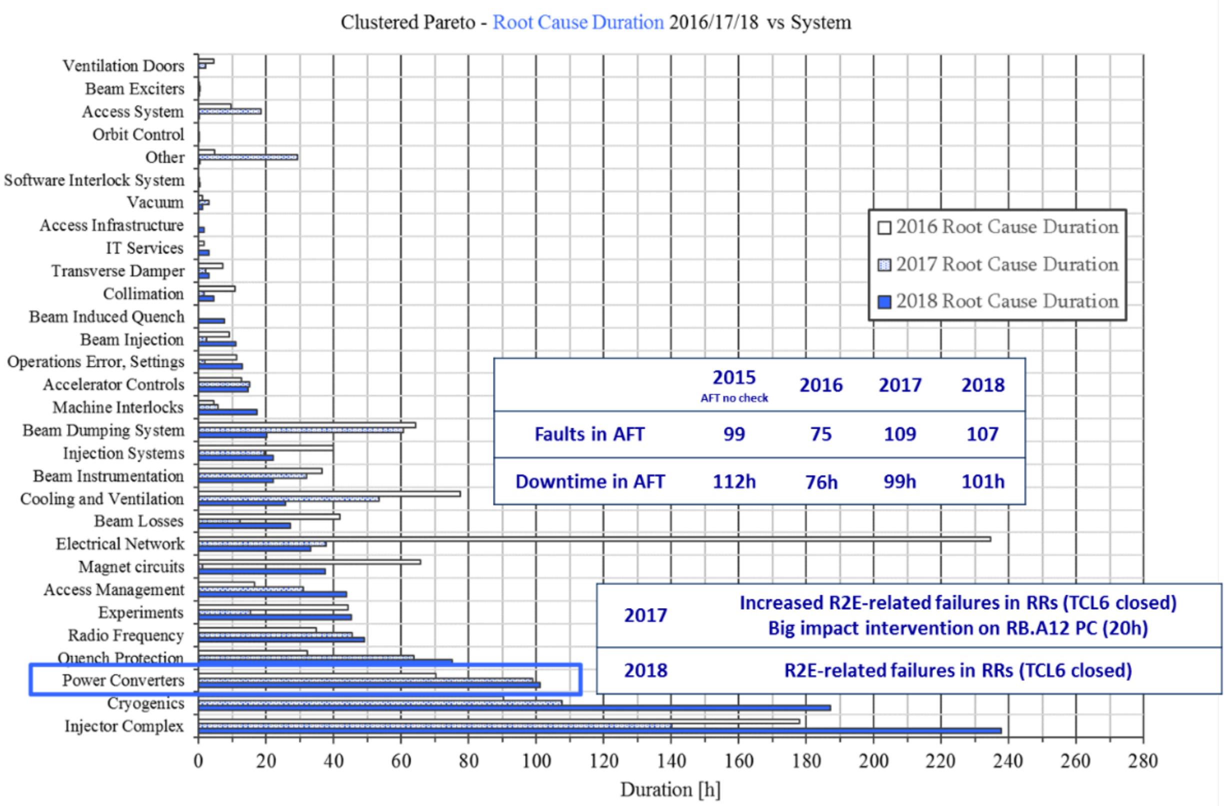

Figure 1: Availability of power converters during Run 2 of the LHC.

parameters on multiple loads, configurations and types of converters.

CONCLUSIONS

Performance of the LHC power converters was stable during the Run 2 of the LHC and the overall fault duration as well as number of intervention seems to be around 100 interventions and 100 hours per year. Consolidation efforts during the EYETS'16-17 to deploy new Saturn power converters and FGClite controls for the 60 A circuits have proven to significantly reduce the downtime. Further R2E mitigations will be put in place in LS2, with the deployment of the FGClite in the 120 A converters in the RRs, together with R2E-600A and R2E-4-6-8kA converters. Consolidation work addresses all known failure modes on main dipole circuits, ALICE compensators and in UA/UJ locations on LHC600A.

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