CHANGES IN POWERING INTERLOCKS

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Abstract

Powering interlocks guarantee the safe operation of both normal and superconducting magnets of the LHC and its injector complex. Experience gained during the last years has served to identify weaknesses of the system and allowed to review some aspects of the existing implementation.

This paper presents an overview of the operational experience with powering interlocks during the first LHC running period (2010-2012). It focuses on the issues encountered, the mitigations put in place and the improvements proposed to be implemented during LS1 that will have an impact on the overall dependability of the machine protection system.

INTRODUCTION

During the first 3 years of operation, magnet powering interlocks have successfully initiated more than 300 beam dump requests coming from different powering systems [1]. Despite the absence of major incidents related to such powering systems, the redundancy of powering interlocks with respect to the beam loss monitors (BLMs) have been compromised in several occasions. Such issues encountered in the past have been carefully analyzed and validated by equipment experts.

The improvements and consolidation measures to prevent such events from reoccurring are discussed in detail in the following.

OPERATIONAL ISSUES AND CONSOLIDATION WORKS DURING LS1

Radiation induced failures

The effect of ionizing radiation on the Programmable Logic Controllers (PLC) has been the main cause of false beam dump requests of the Powering Interlock System (PIC) during the first LHC operational period (2010-2012). A total of five preventive dumps have been triggered by the PIC in 2011 while operating with stable beams at 3.5TeV, following a suspected memory corruption of the PLC due to single event effects (SEEs) that provoked the passivation of the controller outputs.

At the end of 2011 all radiation sensitive components of the PICs installed in UJ14/16 and UJ56 were temporarily relocated to US152 and USC55 respectively. Such mitigation measures were demonstrated to be very effective and prevented the occurrence of SEEs during 2012. In addition, important consolidation works are foreseen during LS1 within the radiation to electronics (R2E) project. A total of 9 powering interlock controllers will be relocated to the bypass areas UL14/16 [2] and UL557 [3]. Moreover, the RD1-FMCM in UJ56 will also be relocated together with the Beam Interlock System (BIS) to USC55.

Following the relocation, all operational databases (i.e.: Layout DB, Logging DB, Alarms…) will be updated according to the new location and naming of the affected systems.

Trips due to electrical network perturbations

One of the root causes of beam dumps from the magnet powering systems in the LHC is due to electrical disturbances affecting the CERN electrical network distribution. Last year a total of 24 of these events were exceeding the defined thresholds of Fast Magnet Current Change Monitors (FMCMs), which led to preventive beam dumps in order to avoid dangerous beam excursions. In most cases (14 out of 24), these glitches were small enough to only trigger the FMCMs while no other equipment trips were recorded (Fig. 1).

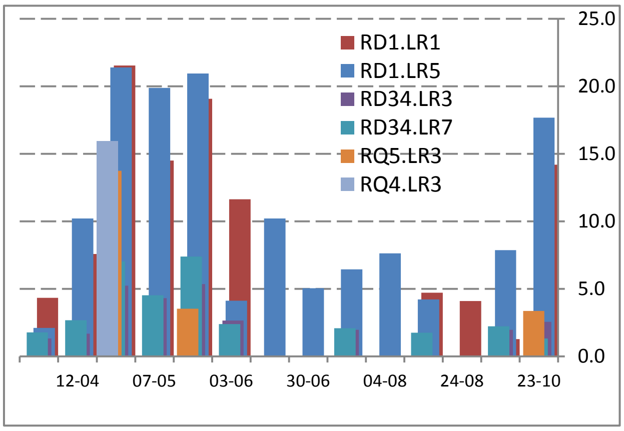

Figure 1: Beam dumps triggered by FMCMs in 2012 with no other equipment affected

An internal review [4] was organized in April 2012 within the TE department with the aim of finding solutions to mitigate the effect of minor electrical network perturbations and consequent FMCM triggers. The review focused on the effect of current changes on the most sensitive circuits: main separation dipoles (RD1), twin aperture main separation circuits (RD34) and the ALICE compensator circuits (RBXWTV). Simulations were presented to evaluate the effect of a typical +300mA magnet current change for the worst possible failure scenario at 450GeV that demonstrated the feasibility to safely relax the existing thresholds in both RD34 and RBXWTV circuit families by a factor 3 [5], as shown in table 1.

Additional mitigation measures are currently under investigation by the TE-EPC group. During LS1, a behavioural model of the thyristor power converters will be made available and the TE-EPC group is confident that a full rejection of minor perturbations can be achieved by changing the regulation characteristics of the most sensitive converters. However, the final mitigation will be the replacement of these thyristor type converters powering RD1/D34 by switch-mode power supplies, which are much less sensitive to network perturbations on the primary side.

Table 1: FMCM threshold upgrade

Electrical circuit	Initial Warning/ Dump Threshold	Modified Warning/ Dump Threshold
RBXWTV.L2	0.5/0.6	1.5/1.8
RBXWTV.R2	0.6/0.8	1.5/1.8
RD34.LR3	0.2/0.4	0.8/1.2
RD34.LR7	0.5/0.6	0.8/1.2

Access and Powering

After the incident occurred on September 2008, new rules were defined to access the LHC underground areas during periods of magnet powering. In order to avoid relying purely on procedures, an ad-hoc interlocking of the LHC access conditions was put in place using the Software Interlock System (SIS) and the LHC timing system. Such solution depends on the Technical Infrastructure Monitoring (TIM) to propagate the access status to the SIS. Despite that the existing implementation has been properly working since 2010, a partial renovation of the system will be implemented during LS1 with the aim of improving the dependability of the communication link based on TIM [6].

The LHC Access Safety System (LASS) will provide the access conditions to a new Access-Powering PLC installed in a neighbouring rack in the CCR (Fig. 2). Then a FESA server will be in charge of propagating the access states to CMW and making them available for the SIS.

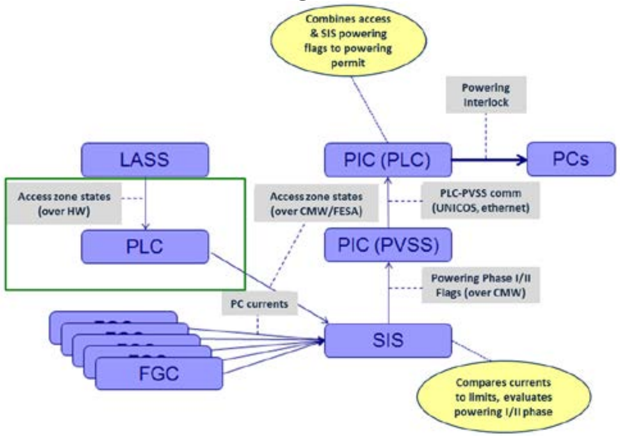

Figure 2: New layout of Access-Powering Interlocks

SPS magnet interlocks

The protection of the normal conducting magnets on the SPS accelerator complex relies on three different interlock systems, which are grouped by circuit families: mains, auxiliaries and ring-line. While the main and auxiliary interlock systems are split per BAs, where the interlock signals from two half-sextants are handled, the ring-line interlock system is made of interlock loops going around the SPS and terminated in a single rack installed in BB3. On the 2th of June 2012 a problem with the ring-line interlock chassis caused several hours of SPS downtime, and was finally traced back to an increase of the impedance of the line over time.

Due to the lack of diagnostics and the difficulties to maintain such an old system dating from the 70's, a new interlock system based on the standard WIC solution will be put in place during LS1[7]. The new interlock system will reuse the existing cabling infrastructure except for the ring-line interlocks that will be split in half sextants (Fig. 3)

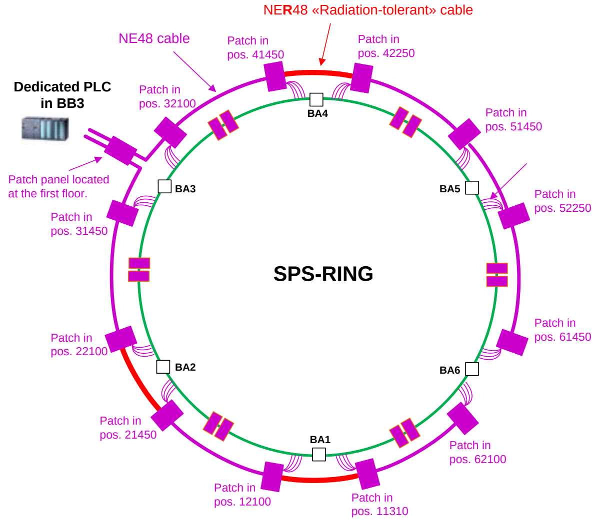

Figure 3: Ring-line interlocks in SPS ring after LS1

Late dump detection by Power Converters

Two issues have been discovered in 2012 when power converter trips provoked beam losses and beams were dumped by BLMs. On the 15th of June 2012 a broken diode inside a triplet power converter caused large circulating currents across the nested converters, which ultimately provoked beam losses [8]. This event was only detected by the FGC controls 300ms after the first current excursions due to the very relaxed interlock thresholds.

On the 7th of September 2012 a radiation induced latch-up affecting the FGC, provoked a 2 seconds delay in sending the powering failure to the PIC. This is caused by a watchdog which keeps the converter running for up to 2 seconds in the event of an FGC crash, to allow the FGC to reset and then to recover the control of the converter.

During LS1, FGC2 will be upgraded to achieve better sensitivity by reducing current threshold settings. In addition, the 2 seconds timeout will be removed to avoid late dump detection.

Late dump detection by Experiments

Protection of the magnets used in the four LHC experiments relies on the Magnet Safety System (MSS). Despite the smooth operation of the MSS, two important events have been recorded last year [9]. On the 10th of August a trip of the CMS solenoid (Fig. 4), caused by a cooling problem, provoked high beam losses along the machine. This fact demonstrated that the solenoid has a slow but non-negligible effect on the beams. MPP has requested that the MSS has to provide an interlock in case of fast discharges. These changes will be implemented during LS1.

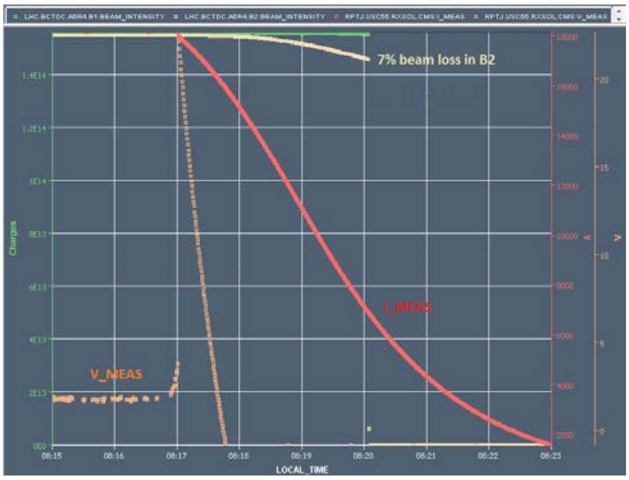

Figure 4: Beam losses after discharge of CMS solenoid

On August 19th beam losses were observed after a trip of the LHCb magnet. This is explained by the fact that the MSS takes some 25ms to generate the interlock event. In order to mitigate this problem, the MSS will be upgraded, including the replacement of the slow output safety relays by optocouplers.

Loss of 60A powering permit

Protection of the LHC 60A dipole orbit corrector magnets is ensured by Power Converters and no hardware interlocks are present. However, non-critical software interlocks prevent unnecessary magnet and current lead quenches and help operations. The PIC-PVSS provides a 60A Powering Permit for each LHC sector, which is derived from cryogenics and powering conditions and then transmitted to the FGC gateways using the LHC timing system.

On the 25th of October 2012 the 60A orbit correctors in sector 56 experienced a slow power abort due to a network communication problem and the following removal of the powering permit by the PIC-PVSS. This event lead to beam losses and the beams were dumped by the Beam Loss Monitors (BLMs). The cause of the problem was traced back to a wrong implementation of the logic in PVSS in charge of calculating the 60A Powering Permit. In addition, a second issue was found: the timing system should have inhibited sending the telegram to abort powering if beams are present in the machine [10].

During LS1, the PVSS interlock logic for the small dipole orbit correctors will be changed and the mechanism to mask such interlock in the timing system if beams are present will be reviewed.

Operational improvements

The protection of the LHC superconducting magnets is ensured on a circuit-by-circuit basis. On top of this and in order to prevent propagation of quenches across neighbouring magnets within the same powering subsector, a global protection mechanism has been implemented in the PIC. Experience over the past years has demonstrated that this implementation represents a bottleneck for testing during hardware commissioning periods since it excludes testing circuits of the same subsector in parallel.

A proposal to allow masking the global protection interlocks via PVSS has been presented to the MPP [5] and will be implemented during LS1. MPP recommended that masks have to be automatically removed if beam permit loops are armed and beam can potentially be present in the machine.

SUMMARY

Powering Interlocks have been working with no major issues during the first years of LHC operation. A huge effort has been put to detect and understand unexpected events and, as a consequence, some changes have been proposed to continue improving the dependability of such interlock systems. All changes or upgrades described in this document have been previously validated and approved by the TE-MPE group and/or MPP.

Considering the non-negligible number of modifications that will be carried out during LS1, special care will be taken to fully validate the interlock systems during the next hardware commissioning campaign.

ACKNOWLEDGEMENTS

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