10th ICALEPCS Int. Conf. on Accelerator & Large Expt. Physics Control Systems. Geneva, 10 - 14 Oct 2005, PO2.036-3 (2005)

POWERING INTERLOCK SYSTEMS AT CERN WITH INDUSTRIAL CONTROLLERS

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ABSTRACT

Several systems at CERN to protect both superconducting and normal conducting magnets are realised with commercially available industrial PLC's, however, their challenges are slightly different.

The Powering Interlock Controller (PIC) for superconducting magnets permits powering when all conditions are fulfilled by communicating with Power Converters and the Quench Protection System. In the case of failure, magnet powering is stopped and the beams are dumped. The response time must be in the order of a few ms. Safety is of utmost importance and critical signals are additionally routed outside the PLC.

The Warm Magnet Interlock Controller (WIC) protects the normal conducting magnets from overheating by switching off the power converter when a fault occurs. One system recently became operational, protecting about 300 magnets in the 3 km long transfer line from the SPS to LHC. In order to optimise safety for future installations, the Siemens F Series PLC is being used, offering a self checking safety environment that ensures system integrity. The same technology will be used for a number of accelerators, in particular the LHC. Before deployment in the LHC, a configurable system has been designed and commissioned for the ion accumulator LEIR, demonstrating the flexibility of using the PLC based system.

In this paper we describe the architecture and implementation of the magnet interlock systems, and discuss first operational experience.

INTRODUCTION

At CERN, there are a number of particle accelerators linked via many beam transfer lines. The most current is the LHC accelerator under construction. This new accelerator is to set a new precedence in the world of particle physics, but more importantly it is setting new requirements to the engineering world.

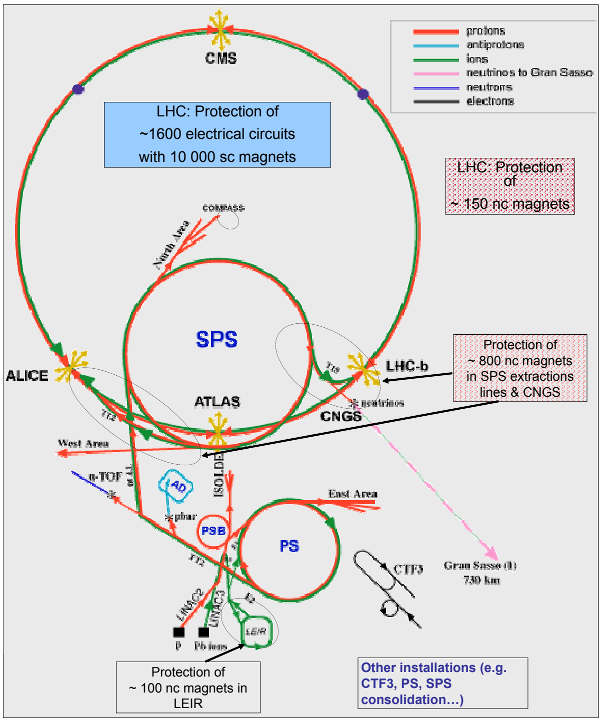

Figure 1: Overview of the CERN accelerators and magnet interlock systems

The LHC will use superconducting and normal conducting magnets to guide and focus the two particle beams through the 27km of the ring. The complexity of the installation is unprecedented, with 1600 electrical circuits powering ~10,000 superconducting magnets operating at 1.9 K and 4.5 K, together with ~150 normal conducting magnets (Fig. 1). Operation relies on adequate and reliable magnet protection systems.

The protection systems for LHC magnets are realised with industrial controllers. PLC industrial controllers and the associated hardware accomplish our goals on many fronts; they must be modular and flexible, operate within our operational speed specifications, safety environments must be supported, and remote IO should be radiation tolerant.

There are many similarities for the protection of normal conducing and superconducting magnets, but with different needs of complexity and speed. For the normal conducting magnets we use a system based on the Siemens PLC 300 series, and for the superconducting magnets we use the Siemens PLC 400 series.

Besides the vast number of magnets in the LHC to be interlocked, many magnets in the existing and new accelerators, together with their transfer lines (e.g. LEIR, CTF3, TI2, TI8, …) are to be protected by such interlock systems. The strategy is to deploy generic and configurable interlock systems based on PLC's not only for the LHC, but also for the other installations. Renovation of the interlock systems with PLC based systems in other existing accelerators will be done when required, for example, in case of aging material.

MAGNET AND POWERING SYSTEMS

In the event of a failure, the protection systems need to switch off the current source and trigger the systems for extracting the energy from both the magnets and the beam, preventing beam induced damage and removing the current in the electrical circuit thus protecting the magnets and the power converters.

Normal Conducting Magnets

Normal conducting magnets have a relatively simple concept to their operation; a controllable power source connects either one or several magnets. Attached to each magnet are several thermo-switches that open the protection circuit if a magnet temperature exceeds 65^0C (see Fig.2). The fault temperature threshold is well below the critical temperature of the magnets, but far above their normal operating temperature, thus providing some time between detection of the over temperature (MAGNET_OVERTEMPERATURE) and damage to the magnet. For the power converter we have two binary interface signals, one to give permit for the converter to operate (PC_PERMIT), and the second to receive the status of the power converter in case of internal converter failures (POWERING_FAILURE).

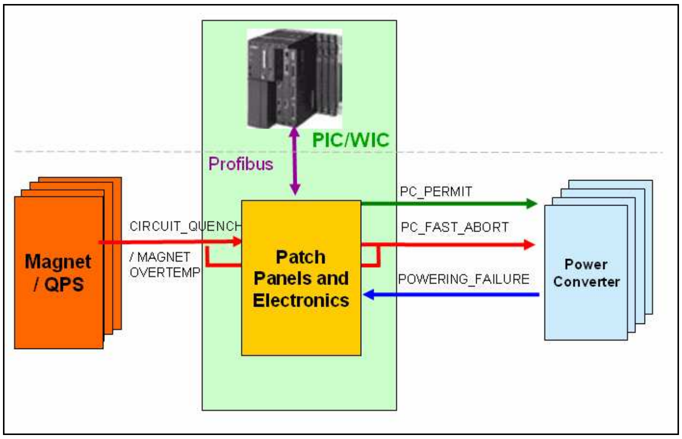

Figure 2: PLC protection system overview

Each magnet interlock could be hardwired to the power converter, however as the converter is connected to several magnets who's thermo-switches are connected in series, the thermo-switch which caused the failure is not indicated, and valuable time is lost in fault finding. The WIC can diagnose the system remotely via a supervision system, and the fault can be identified before repair, thus minimising intervention time and possibly limiting the exposure time of personnel if the magnet is installed in a radioactive environment. Compared to previous systems, the complexity has been moved from the level of the hardware (e.g. patch panels) to the level of software, which is more flexible, easier to maintain and develop.

The objective is to detect and stop a circuit when an over-temperature occurs, request a beam dump and signal this to the supervision system. On the detection of a failure, the Beam Interlock Controller [1] is signalled to issue a beam dump request. Secondly, to protect the magnet, the permit signal to the converter is removed; the power converter switches off and the current in the magnet decays. The required speed of response is in the order of several seconds or more, for this system we have used the small Siemens 300 series controllers.

The WIC is the only protection system in place for normal conducting magnets. To increase the protection level, the WIC has evolved to use F-Series safety PLC instead of the standard PLC series. A safety PLC offers a greater level of protection and within the response time permitted (<1s). The system performs self testing of its own hardware and software to detect failures and corruption, and goes into a safe state in the event of an abnormality.

Superconducting Magnets

The Powering Interlock Controllers for superconducting magnets have a more demanding task as protection system. After a quench in a superconducting magnet, the maximum response time to protect accelerator components from the beam becoming unstable can be as small as one ms. Protection of the components in the electrical circuit such as magnets and power converters must be ensured within some ms.

There are three systems in each electrical circuit directly involved in its protection, the Power Converter, the PIC, and the Quench Protection System (QPS), and for each protection circuit several control signals are exchanged between the systems (see Fig.2 and Fig.3). Any system can detect an error and take evasive action.

When dealing with a complex system with a ms reaction time, the smaller and less sophisticated 300 series PLC used by the WIC system is not viable, and the Siemens 400 series with its faster and more powerful CPU was chosen.

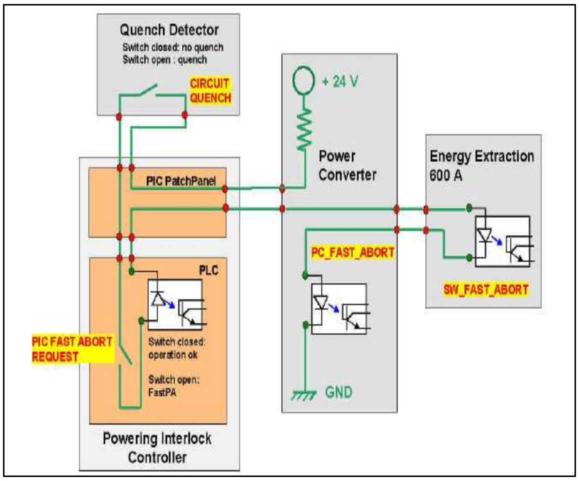

Figure 3: An example of the signal exchange between PIC and the other systems.

The PIC and its connected systems are designed for speed and redundancy. This is achieved by hardwired current loops for each protection signal that link the three systems.

Since redundancy is realised outside the PLC via hardware, a standard PLC and not a safety F-Series was chosen, this allowed us to realise the maximum speed from the PLC's operation and the software was designed to achieve the goal of a maximum response time of <10ms.

The PIC provides the redundancy and additional operational functionality expected from an intelligent system. Within one powering-subsector of the LHC all the magnets are installed in the same cryogenic environment, in the LHC there are 28 such subsectors. In the case of a quench in one magnet if no measures are taken, many magnets in that section could quench. The PIC will therefore shutdown the converters supplying the other magnets in a controlled manner, stopping a quench from propagating through the whole cryogenic environment, and so saves valuable cryogenic gasses and energy. This also reduces the time for recovery from the failure, thus saving much desired beam time.

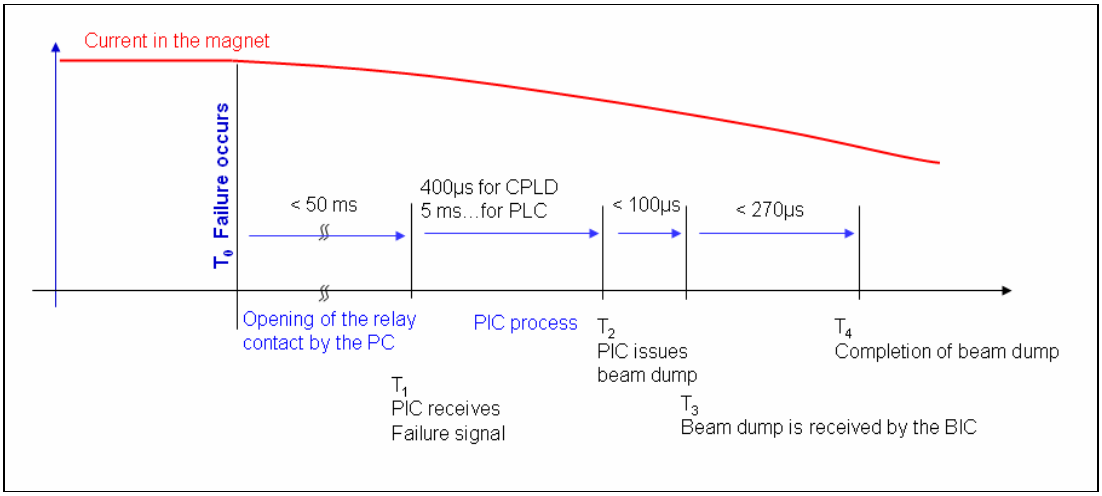

Figure 4: The superconducting magnet protection time frame, with individual system reaction times

The equipment is remotely monitored via a supervision system allowing remote diagnostics. The higher level system facilitates automatic event building of the sequence and cause of the failure, highly desirable when considering such complex installation.

OPERATION

The first PLC based system was for the protection of normal conducting magnets in the SPS-LHC transfer lines, for this we used a standard PLC. For protecting normal conducting magnets in the LHC with the WIC as the only guardian, a standard PLC was considered not to be sufficiently safe, and we opted for the F-Series Siemens PLC.

Operation of the PIC has been catered for over different levels:

- The individual circuits are connected to the PLC using current loops which link the Quench Protection System, the Power Converter and the PIC. The diagram in Fig.3 illustrates that each protection signal is hardwired through all the required systems. The PIC's operation is redundant to this, and can in addition request a beam dump and a powering subsector shutdown on selected circuits. The required reaction time is provided by the hardwired current loops, the PIC system needs to react fast to signal a beam dump, and to shutdown other circuits in the same cryogenic environment.
- A number of very critical magnets have a fast decay time in the case of powering failures. We designed into the PIC a redundant system to signal a beam dump. This system uses a CPLD programmed effectively with an OR gate. If any signals within the OR gate drop out a dump is requested with a reaction of <1ms, this is in addition to the PLC's request (see Fig. 4).
- A redundant power supply unit has been added into the PLC rack. The additional power supply significantly increases the availability of the system.

A fault tolerant system was also contemplated; Siemens offers the H-Series PLC's where all components in the PLC are duplicated allowing redundant operation that is transparent to the system. However the radiation tolerant remote IO we use doesn't facilitate a redundant network, and so couldn't be made redundant. The cost to implement two IO systems would be far too great, with respect to the gain in system availability the effect of having a duplicated CPU gave only little advantage.

The diagram in Fig.5 shows the operation the PIC needs to follow. This function is performed via a PLC, with flexibility and ease of connection and communication to other equipment via standard interfaces and communication channels. The 36 PIC systems that are required for 28 powering sub-sectors use the same PLC program and are configured individually from a reference database.

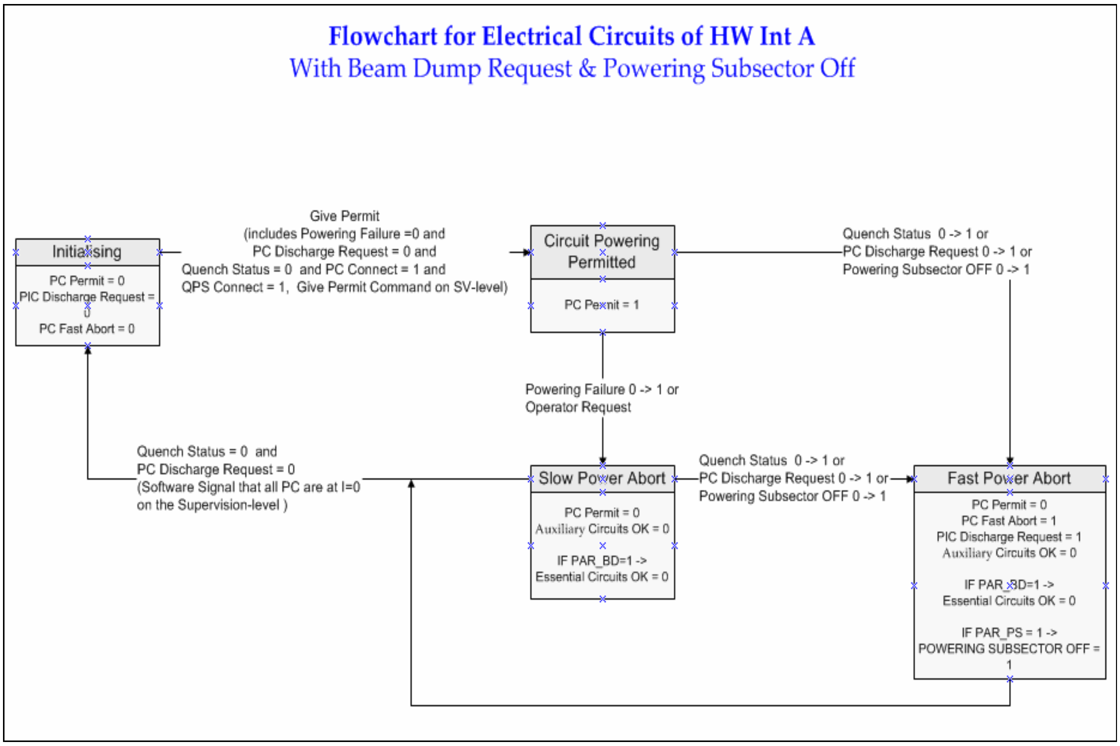

Figure 5: PIC functionality flowchart for main bending and quadrupole circuits of the LHC.

FALSE TRIGGERS

False triggering of a system has been on the design board from the beginning, with a strong emphasis on EMC tolerance. The potential for false triggering being present at the level of each signal input, all connections to the other systems have been designed to be EMC tolerant. This has been achieved by snubbing inputs and outputs with transient voltage suppression diodes, routing internal cables with care, and ensuring all chassis earths and cable earth connections are tight and secure. The system has been tested in conjunction with the other systems to an EMC level 4 (representing a highly perturbed industrial environment), and all systems including the PIC adequately pass the test.

CURRENT STATUS

Currently we have achieved and developed the first production run of both the PIC and the WIC. The WIC has been installed for several accelerators, and has proved successful on the first test run of a transfer line. During the commissioning period several faults of the magnet cooling were detected and effective evasive action was taken by the WIC system.

The PIC has undergone individual system tests, and the first system has been installed and commissioned ready for the first operation tests in the LHC.

A dedicated test system using a Siemens 300 series PLC and high level control software has been designed to facilitate the rigorous and complete test routines that we put each system under in the laboratory before deployment. The test system has proved invaluable through the design stages, and gives us great confidence in each PIC system before it is dismantled, transported and then reassembled in the accelerator environment.

CONCLUSION

Using a PLC in this environment has to a certain extend protected us from obsolescence, Siemens products have been back-ward compatible, allowing a solution to be used for similar systems throughout CERN and potentially for other organizations.

Using off-the-shelf components offers a short lead time from concept to installation, and also facilitates using off site stores supplies, thus reducing the cost tied up in storing large amounts of spares on site.

The PLC's flexibility has provided us with one design that is configurable. Within the physical design constraints each system can be used at other installations with only a change to the configuration file. Thus further installations can be accommodated rapidly, with less design costs, and quite acceptable budgets for inventory, time and manpower.

The WIC system has not only been used for interlocking, but also for monitoring the temperature in the transfer line tunnel. The flexibility of the PLC system allowed for the use of its communication infrastructure, and because we use a low priority area of the PLC program for this task there is no deterioration of the protection system.

The wide nature in the use of PLC's have facilitated other third party systems to be born, one example is the supervision systems that exist. For our application we use PVSS / UNICOS to provide the high level supervision [2].

Using industrial controllers facilitated the use of PVSS to achieve a reliable and usable operator console, each PLC system is autonomous and can operate safely without a supervision system, however efficient operation is only achievable with easy access by an operator.

Industrial controllers have a large understanding throughout the engineering world, although complex machines and processors are realised with PLC's, their operation and maintenance have a wide skill base when compared to bespoke systems built in house, and therefore in the future can be maintained and modified from this skill base.

ACKNOWLEDGEMENTS

The successful implementation of the powering interlock systems was only possible due to the dedicated effort of several colleagues: J. Brahy, A. Dinius, C. Martin, P. Nouchi, M. Zaera Sanz, J.L. Vo Duy and A. Freze.

REFERENCES

[1] B. Todd et al., The Architecture, Design and Realisation of the LHC Beam Interlock System, these proceedings

[2] F. Bernard et al., Deploying the UNICOS Industrial Controls framework in multiple projects and architectures, these proceedings