CONTROL OF THE LHC 400 MHZ RF SYSTEM (ACS)

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Abstract

The LHC ACS RF system is composed of 16 superconducting cavities, eight per ring. Each ring has two cryomodules, each containing four cavities.

Each cavity is powered by a 300 kW klystron. The klystrons are grouped in fours, the klystrons in each group sharing a common 58 kV power converter and HV equipment bunker. The ACS RF control system is based on modern industrial programmable controllers (PLCs).

A new fast interlock and alarm system with inbuilt diagnostics has been developed. Extensive use of the FIPIO Fieldbus drastically decreases the cabling complexity and brings improved signal quality, increased reliability and easier maintenance.

Features of the implementation, such as system layout, communication and the high-level software interface are described. Operational facilities such as the automatic switch on procedure are described, as well as the necessary specialist tools and interfaces.

A complete RF chain, including high voltage, cryomodule and klystron is presently being assembled in order to check, as far as possible, all aspects of RF system operation before LHC installation. The experience gained so far in this test chain with the new control system is presented.

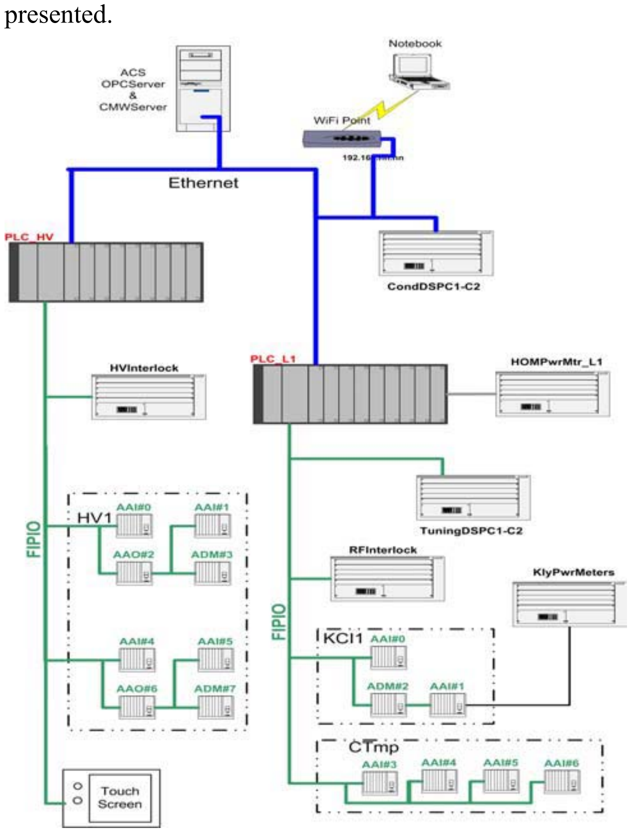

Figure 1: General PLC Layout.

THE LHC ACS RF SYSTEM

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CONTROL SYSTEM LAYOUT

The ACS RF control system is based on modern industrial programmable controllers (PLCs). The type used is the mid-range Premium family from Schneider. Maximum use is made of remote I/O subunits to interface equipment locally, resulting in modularity and minimizing cabling.

The layout is shown in Figure 1. One PLC (LINE PLC) is assigned to each cavity-klystron pair or ‘LINE’. A klystron control interface (KCI) remote I/O unit near the klystron concentrates all the klystron, circulator and load control points. A cavity temperature conditioner interface (CTemp), is situated on the outside wall of the machine tunnel in the cavern. While most control points and slow interlocks are handled by the PLC and I/O units, some equipment is contained in dedicated crates e.g. cavity tuning, fast interlocks on RF and klystron and HOM power meters. Since a group of four klystrons both shares a common power converter and HV equipment bunker and drives the four cavities of one cryomodule, the control of power converter, HV equipment and the cryomodule is conveniently handled by a common PLC (MODULE PLC). Common data is shared between one MODULE PLC and four LINE PLCs by means of public memory segments on each PLC, using the manufacturer’s propriety protocol (I/O scanning). In this way the sequencing in all five PLCs can be correctly synchronized.

Fieldbus layout

The field bus used is the industry standard FIPIO, a subset of the WorldFip standard. Only the cyclic part of the protocol is implemented, running at a fixed speed of 1Mbit/s. All the remote interfaces, as well as some of the dedicated equipment such the fast interlock and the cavity tuning controller, are connected to the FIPIO using standard I/O modules or OEM interfaces [1].

A FIPIO cycle time of 12 ms has been measured for the LINE PLC with 32 analogue and 32 digital I/O and this more than meets the requirement for monitoring and control, as well as for slow interlocks.

FAST INTERLOCK SYSTEM

The PLC fast cycle is however not fast enough to switch off RF, where the reaction time must be of the order of 1 uS to avoid damage in the event, for example, of an arc. To meet this requirement a fast interlock module has been developed, based on the model used for the LEP RF system.

This module reacts, by dropping the output lines, in less than 1µSec (typical 600ns) to a fault on any of its eight inputs. The path from detection to action is in hardwired logic, programmed in a CPLD. All the faults are latched and stored until a reset is performed; the first fault is also discriminated against. An on-board microcontroller is in charge of the fault detection, buffering and communication to the main CPU module of the crate.

The CPU module contains two industrial OEM boards [2]. The first collects the data from the interlock modules (eight maximum) through an I2C backplane bus and passes it to the second which transfers it to the PLC via the FIPIO interface.

THE SEQUENCER

The PLC sequencer

The PLC is considered as an embedded part of the equipment; it has a key role in the security and protection of the equipment as well as its function in the overall control and surveillance of the RF systems.

In the LINE PLC a series of software modules ensures both the proper sequencing of all the devices and their appropriate automatic surveillance, depending on their actual state.

The Sequencer is split in levels, each level is composed of a number of steps and each step has a command and an acquisition status bit.

When the command is issued to move to higher level the steps are executed sequentially; the previous step acquisition must have been completed and a correct status returned before the next step is initiated. A fault bit is also associated with each acquisition input and used in the monitoring process.

The PLC software is organized in modules, each dealing with a device (ex. power supply), with a standard interface to the sequencer. In the event of a problem the sequence can be stopped at any step, manual control of the device can be taken, or status bits forced to allow debugging.

The local surveillance screens

The sequencer can be driven remotely or by a local command screen.

The local command screen is based on a 10” colour touch screen connected to the PLC via FIPIO. Its main use is for specialists during commissioning and maintenance. A number of pages can be also displayed: sequencer states, specialist parameters, alarms and faults as well as system parameters.

In order to give control to the higher level supervision program a key has to be turned to its remote position. A special position called disabled will put the system in a secure OFF state during human intervention, by hard-wired power switch off.

HIGH LEVEL SOFTWARE AND COMMUNICATION

Integration in the LHC control structure

Remote control, surveillance and diagnostics facilities must be fully integrated into the LHC control system. Industrial PLC technology is used for the Power and RF controls and low level RF systems are VME based, containing a large amount of complex custom RF and digital electronics. The control system will be based on the standard 3-tier architecture, the central point for communication between power and low level systems being in the middle tier, in front end servers. Communication between applications, servers and equipment will be based on CERN in-house standards.

Data exchange between servers

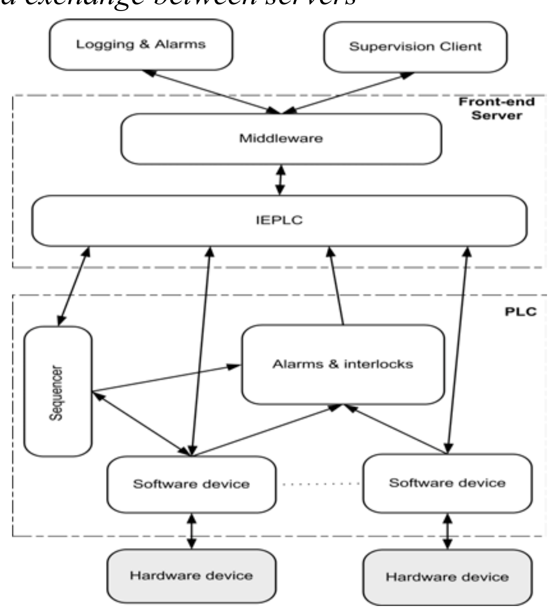

Figure 2: Software architecture.

The PLC data transfer and system monitoring will be done using a CERN developed protocol called IEPLC. This protocol is based on Modbus/TCP and is compatible with a wide range of PLC manufacturers. The protocol contains a suite of configuration tools to create classes and devices reflecting the PLC data, in a form compatible with the high level software. Standard tools will allow transfer of data to the LHC alarms system LASER [3] and the logging system. [4]

Expert and operators interfaces

Last but not least in the control chain there are the user interfaces. Two types will be developed: one for the operators, to be fully integrated in the LHC machine control sequencing application, the other for the RF equipment specialists. The operator interface will control the ON/OFF/Reset commands for each RF LINE and will receive a summary faults message.

The specialist applications will display all the parameters. A suite of fixed displays will also be generated from the same data. All the user and operator applications will be written in Java and will run on Linux consoles in the new CERN Control Centre. (CCC)

TEST STAND INSTALLATIONS

Building blocks and layout

The test and validation of the LHC ACS RF system and its control system is ongoing in three different test areas,
1) The klystron and RF power test stand,
2) The power couplers test and conditioning facility,
3) The main SC cavity test area (SM18 building).

In the latter a full test chain, including power converter, HV equipment, cavity, low level RF and controls is being constructed.

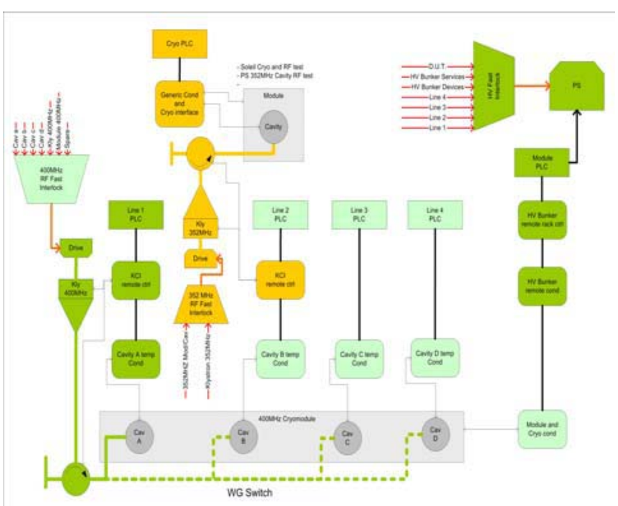

Figure 3: SM18 Test stand block diagram

High power system commissioning

The first two test stands have been fully upgraded with the LINE PLC systems for klystron and power controls. Reliability and the basic operational facilities meet the requirements of LHC operation. The klystron RF power system and the high voltage control were installed in SM18 at the beginning of 2004. In the power couplers test stand, the installation was done in 2 weeks and after a small period of setting-up and calibrations (RF power meters, water cooling circuits etc.) the full RF power (300KW at 400.8MHz) was operational.

In the SM18 test area, transfer of RF power from the klystron to a given cavity is by means of a sophisticated waveguide switching system. The first four power couplers and cavities were successfully conditioned to well above the nominal field (5 MV/m) in a very short time.

Cavity and cryomodule commissioning

The final implementation of the MODULE PLC is currently being tested in the SM18 test area. The cavity and cryogenic control interface has been installed. The cavity temperatures are collected by a remote I/O sub-system composed of 13 dual temperature conditioners [5] and related acquisition modules. Cryomodule parameters (helium levels and pressures) will also be connected by another remote wall mounted I/O controller. This version of the controller will include the PID controllers for the main coupler window and cavity cone heaters. A separate PLC has been installed to implement the interface and transfer of data between the cryogenic plant and the RF control system.

CONCLUSION

Maximum modularity has been aimed for in the design, with extensive use of field-buses to simplify the interconnections. The hardware has been kept as simple as possible, with maximum use of industrial components. The HV and RF control systems have been validated and the cavity and cryo systems are nearing completion.

The next stage will be to verify all aspects of the complete system during long-term operation and to build up the application software. This program will be completed in time for LHC installation in 2006.

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REFERENCES

[1] http://www.anybus.com/eng/default.asp
[2] http://www.phytec.de
[3] http://proj-laser.web.cern.ch/proj-laser/
[4] http://lhc-logging.web.cern.ch/lhc-logging/
[5] http://modules-doc.web.cern.ch/modules-doc/