17th Int. Conf. on Acc. and Large Exp. Physics Control Systems ICALEPCS2019, New York, NY, USA JACoW Publishing
ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-MOPHA103

THE PLC CONTROL SYSTEM FOR THE RF UPGRADE OF THE SUPER PROTON SYNCHROTRON

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Abstract

During the CERN Long Shutdown 2 (LS2), the 200 MHz main acceleration system of the Super Proton Synchrotron (SPS) is being upgraded. Two cavities will be added to reach a total of six. Each new cavity will be powered by Solid State Power Amplifiers (SSPA) grouped into 16 "towers" of 80 modules each, in total 2560 modules. This paper describes the newly developed control system which uses a master PLC for control and interlock of each cavity and the slave PLC controllers for each of the solid state amplifier towers. The system topology and design choices are discussed. Control and interlocking of all subsystems necessary for the operation of an RF cavity are detailed, and the interaction between the master and slave PLC controllers is outlined. We discuss some preliminary results and performance of the test installation.

INTRODUCTION

During the long shutdown 2 (LS2), the LHC injection chain is being updated to increase the beam intensity supplied to the LHC in order to increase the collision luminosity [1].

In the SPS, the 200 MHz main acceleration system is being upgraded for this purpose.

It will go from 4 TWC (traveling wave cavities) with 2x4 sections (Fig. 1) + 2x5 sections to 6 TWC of 2x4 sections + 4x3 sections (Fig. 2)

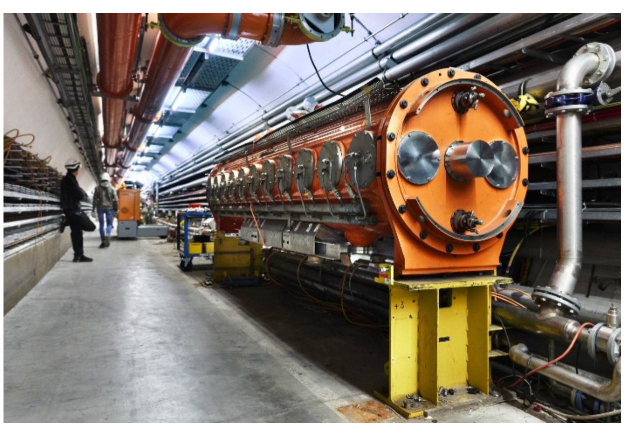

Figure 1: One section of 200MHz TWC.

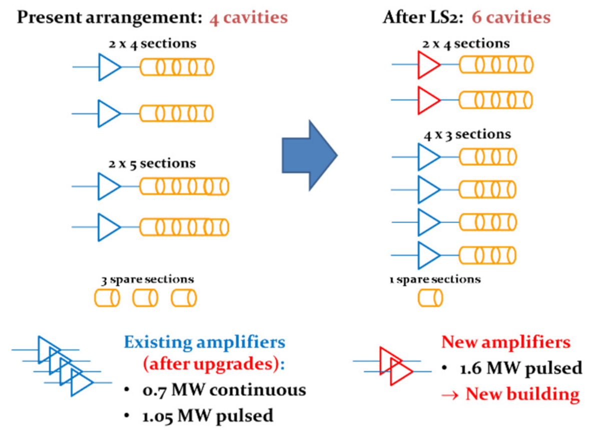

Figure 2: Renovation of 200MHz TWC system.

The two new cavities, of four sections each, will be powered by a new solid-state amplifier chain that will provide 1.6 MW to each cavity.

The other 4 cavities, of 3 sections each, will continue to use the old tube amplifiers with 1.05 MW each.

The whole system (Cavity, amplifiers, etc.) is controlled by PLCs (programmable logic controllers).

In this article, we will focus on the control system of the solid-state amplifiers.

THE NEW SOLID STATE AMPLIFIER

The new amplifier chain is composed as follows (Fig.3):

- The RF signal is generated by the beam control (Low Level RF system)
- Two fast RF switches, one on the Low Level side (LL RF Switch), one on the high level side (HL RF Switch)
- 16 pre-drivers (TTis) of type TTi Norte SSPA (Solid State Power Amplifier) delivering 1250 Wp each (Fig. 4). The RF drive signal is split in 16 to feed the 16 pre-drivers.
- 16 Thales towers, with 80 SSPAs each, which deliver 115 kWp per tower. The output signals of the 80 SSPAs are combined to power the cavity.
- The RF signal to the cavity will be 1.6MWp

THE NEW CONTROL SYSTEM

The new control system is composed as follows (Fig. 5):

- A master PLC of the brand Beckhoff
- Sixteen tower controllers of the brand Beckhoff
- An in-house designed fast-interlock system coupled with an analog acquisition system to monitor RF signals
- A FESA server running on FEC

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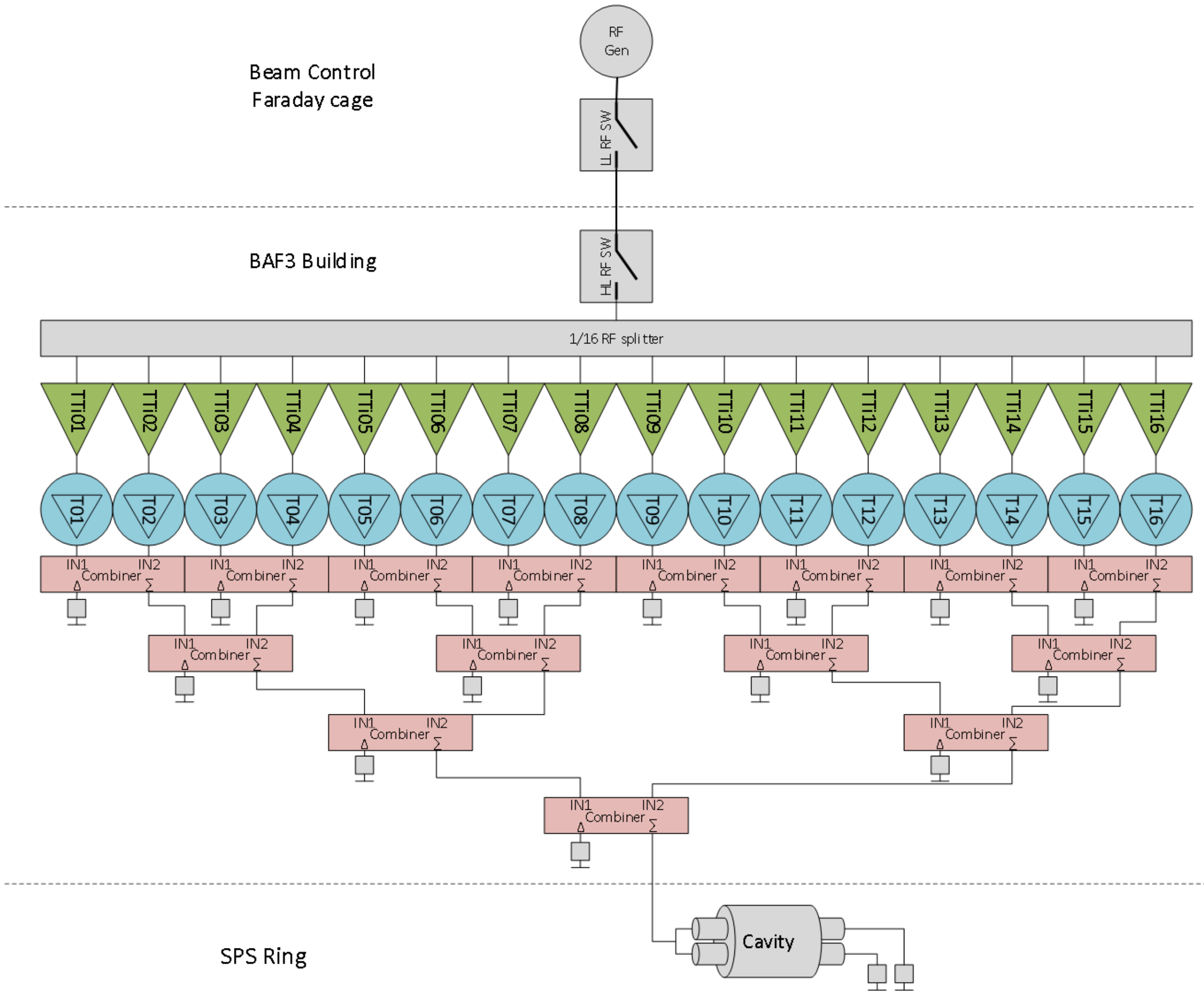

Figure 3: Overview of the new TWC SSPA system.

Figure 4: TTi SSPA pre-driver.

Master PLC

The main features and functions performed by the Master PLC are:

- Hardware signal acquisition of several devices:
  - Cavity services (blower, pumps, etc)
  - The 16 TTi SSPAs
  - The 16 tower PLCs (Fig. 6)
  - The fast interlock
  - The hybrid combiners
- 2 modes of control: local or remote. In remote mode, the system acts according to the received commands from the CCC (CERN Control Center) and returns the state of the system. In local mode, the system is controlled via a touch screen, which acts as a GUI (Graphical User Interface), and implements more features for the specialists.
- Local monitoring and supervision of the whole system by means of a GUI (Graphical User Interface). The system GUI allows RF specialist to modify the cavity operation mode and system configuration settings, send cavity control commands, and follow the interlock sequence evolution. It also gives visual information by means of different colors in case of faults or warnings and indicates in which part of the system these happened. Furthermore, there is a dedicated tab for the Tower PLCs where it is possible to monitor the status of every tower as well as modifying manually their specific settings and setting them to ON or OFF.
- Communication with the Fast Interlock system by Ethernet using Modbus TCP

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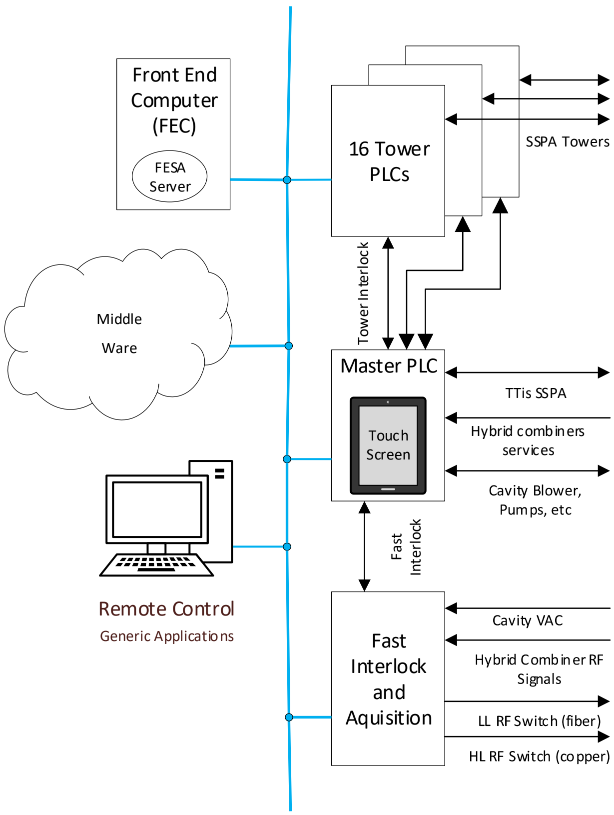

Figure 5: Control diagram.

Figure 6: Amplifier hall with 32 towers.

- Framework communication with the tower PLCs by means of the Beckhoff ADS protocol. The communication is carried on continuously by means of commands sent by the master PLC and status received from the Tower PLCs.
- Event handling and fault registration**.** System events such as faults, warnings or information messages concerning the sequence evolution are continuously registered and shown in the GUI. These messages can come from either the master or the tower PLCs.
- Continuous storage of critical system data such as timeouts, event history, software version or the towers' communication settings, performed every time there is a change in the system or a modification by the operator.
- Selection of the cavity operation mode, local or remote, according to the RF specialist's choice, and processing of cavity control commands such as ON, OFF, STANDBY, or RESET depending on the RF specialist's orders.
- Startup interlock sequence, where a series of critical conditions are checked. These conditions have to be accomplished in order to assure a proper startup of the cavity and they also need to follow a specific activation sequence.
- This sequence is divided into 3 Levels, corresponding to the different critical systems and/or services of the cavity:
  - Services level (Level 1), where the air blowing & water pumping services are checked.
  - RF powering level (Level 2), where the TTi amplifiers and the Towers are properly set.
  - Fast Interlock level (Level 3), where the most critical systems connected to the PLC master are checked, such as the vacuum service, the emergency switch or the RF switch.

<u>Tower PLC Controller</u>

An SSPA tower (Fig. 7) contains 80 amplifiers. These amplifiers are water-cooled and are powered by 400V three-phase.

Each tower has several service signals:

- 400V detection
  Analogue signal for water temperature
- Analogue signal for water flow
- Digital signal for water leak detection

Each SSPA uses a control signal and two status signals all connected to the PLC (80 outputs and 160 inputs).

There is also a wired contact called 'interlock' between each tower PLC and the master PLC. This cable carries two important signals:

The "Tower Enable" signal is activated by the master PLC to allow switching ON of the SSPAs.

The "Tower OK" signal is activated by the tower controller if there is no fault.

The "interlock" cable is very important in the case of loss of Ethernet connection and if one needs to turn off a tower very quickly. An OFF command over Ethernet takes a few hundred milliseconds, while through the interlock cable it only takes a few milliseconds.

Figure 7: Thales SSPA tower.

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The tower PLC is also a Beckhoff controller and performs the following tasks:

- Monitors signals from the services (water temperature, water flow, etc) and cuts all the amplifiers in case of fault
- Monitors the signals of the amplifiers and cuts the faulty amplifier in the event of a fault
- Receives commands from the master PLC and executes it
- Returns the state of the tower to the master PLC
- Keeps the list of faults in memory and sends them to the master PLC

When a "Tower ON" command is issued the tower controller sequences the switch-on of the amplifiers, waiting until the previous amplifier is ON or Faulty before trying to activate the next one. The goal is to avoid the intense supply current peak which would occur if all the tower amplifiers were switched on at once.

When powering on the SSPA, the PLC performs the following steps:

- It verifies that the SSPA has not been turned OFF in the last 80 seconds. If so, it waits 80 seconds before going further. This must be done to discharge the amplifier capacitors
- It checks that the services are OK (water temperature, water cooling and 400 V), that no other SSPA is starting up and that the signal "Tower enable" is activated
- It activates the ON output of the amplifier
- It waits 100 ms for the two SSPA state signals to become OK. If these signals are not OK within 100 ms, the SSPA is set in the FAULT state and the hardware output is disabled

Fast Interlock and Analog acquisition

This system (Fig. 8) is responsible for acquiring analogue signals received from hybrid combiners. These signals indicate the "forward" power and the "reverse" power values.

The fast interlock activates the LL RF Switch via an optical fibre and the HL RF Switch over a copper cable if the state of the system is OK. We use a fibre optic for the LL RF SW because it is placed inside a Faraday cage.

The fast interlock system checks selected "reverse" signals, the cavity vacuum and the "PLC Master OK" signal. If one is missing, the two RF switches are opened. The master can check the status and send a reset command.

Figure 8: Fast interlock crate.

CONCLUSION

The controllers for the SSPA towers are all installed in the new amplifier hall. During the last 3 months, six towers and their controllers have been fully tested. The others will be tested following the reception of the SSPAs from Thales.

A full system test of 16 towers, with the master PLC and the fast interlock system, is planned by end of 2019. The final hardware test of the two new cavities will be carried out starting September 2020.

Remote control will be implemented using the standard tools from CERN's Controls group.

ACKNOWLEDGEMENTS

The authors would like to thank Eric Montesinos's team in the CERN BE/RF/PM section, which has actively participated during the design phase of the system, and all the technicians from the CERN BE/RF/CS section for the construction of the required hardware.

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