UPGRADE OF THE ELETTRA MAGNET POWER SUPPLY CONTROLLERS

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Abstract

Ageing of devices and components phasing-out, as well as the increasing maintenance costs affect particle accelerators similarly to any industrial plant. A careful maintenance plan can cope with these problems in the medium-term and then a complete update of the oldest parts is required. The most recent technologies available on the market, together with a modular and open design approach are the basis of an upgrade program aimed at replacing the existing controllers of the Elettra storage ring magnet power supplies. The design considerations, the constraints and the first results are here reported.

INTRODUCTION

Elettra is the Italian third generation Synchrotron Light Source operating for users since 1994. Its time line is reported in Fig. 1.

In its original form, the Elettra Storage Ring (SR) was at first filled by a 1 GeV linac, and then "ramped" to the final electron energy of 2.0 GeV. Since 1999 the 2.4 GeV energy is also available for the 25% of user dedicated time. Due to time synchronization constraints, the energy ramping procedure was strongly in charge of the power supplies (PS) and their control system.

During 2008 a full energy booster, fed by a 100 MeV linac pre-injector, was built [1]. Since 2010 the SR operates in top-up mode both at 2.0 GeV and 2.4 GeV [2].
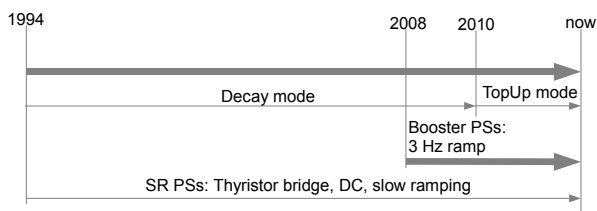

Figure 1: Elettra time line.

The original storage ring power supplies and their control system are still working fine, nevertheless components ageing and phasing-out, difficult spare parts availability and system reliability are strong arguments for a renewal. Moreover, a new control system can benefit from technology evolution of both hardware and software, thus providing better performance.

These considerations led us to plan an upgrade program aimed to refurbish the PSs controllers and simplify their remote control network.

CONTROL SYSTEM OVERVIEW

The Elettra power supplies control system is based on a three layers architecture [3,4], as shown in Fig. 2.
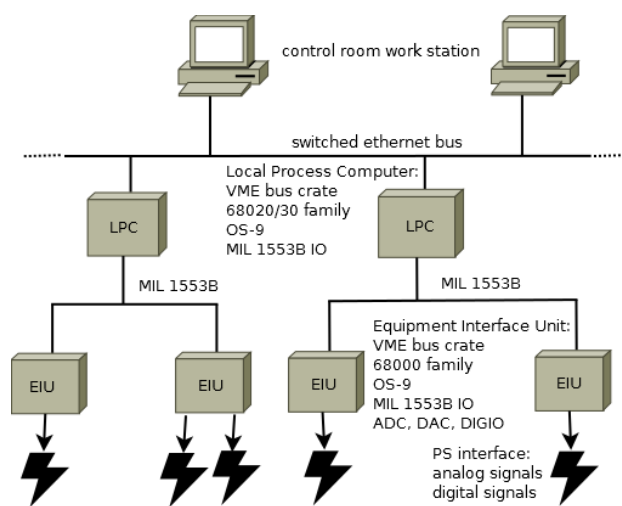

Figure 2: PSs control system layers.

The top layer consists of the control room work stations that are in charge of the presentation layer, e.g. operator panels and high level software. All these workstations are connected to the rest of the control system by a dedicated Ethernet network.

The middle layer consists of Local Process Computers (LPC) that manage the remote control of a family of homogeneous devices. LPCs are based on VME crates hosting ELTEC 68k CPU boards and running the OS-9 real-time operating system. Each LPC is connected to the control system Ethernet network and acts as the master for the MIL-1553B field bus connecting the LPC to the bottom layer devices. Each LPC routes the commands from the top layer to the appropriate bottom layer device. The LPCs also implement some global procedures involving groups of power supplies such as the magnets cycling process.

The bottom layer computers are the Equipment Interface Units (EIU); each EIU interfaces one or more PSs by means of several analog and digital signals connected to the PS local electronics (Fig. 3). The EIUs are based on VME crates hosting the same family of CPU boards used in the LPCs, and several dedicated input-output boards. Each EIU is a slave node of the MIL-1553B bus.

Each PS is controlled acting on its interface signals and provides current to one or more magnets (sextupole, quadrupole or bending), indicated as "load" in Fig. 3.
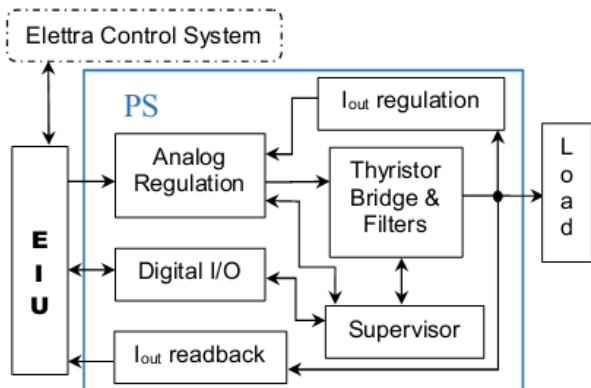

Figure 3: Power supply block diagram.

The load current, measured by a dedicated DCCT (Direct Current Current Transformer) is controlled by an analog feedback loop tracking the set point provided by the EIU. An additional DCCT is used for monitoring the generated current. A set of digital I/O signals is used for reading states and alarms (PS interface outputs) and sending commands (PS interface inputs).

UPGRADE CONSIDERATIONS

During the last 15 years, thanks to the availability of new technologies, several parts of the original control system have been renovated. The control systems of radio frequency plants, vacuum system and insertion devices have been successfully updated, improving the performance and simplifying the control system layout.

Due to the high number of devices involved, the complexity of the system and the absence in the past of a full energy injector, the PSs control system has not been upgraded yet and is still adopting the original architecture.

Upgrade Goal

The goal of the power supply control system upgrade is to replace the VME based control system with state-of-the-art equipment.

The main requirements are:
- to simplify and optimize the present system architecture (i.e. merging the middle and bottom level functions of the control system in a single controller directly connected to the PS);
- to add new features that were not added before either due to hardware/software limitations or new requirements raised over the years;
- to adopt an open design approach;
- to extend the PS control system lifespan by at least 10 years.

Upgrade Constraints

Being one of the vital systems of the Elettra SR, the PS control system upgrade has to deal with the following constraints:
- reliability over time (Elettra operates for 6400 hours/year);
- stability over time of given characteristics;
- the interface between the control system and the power supplies local electronics must not change;
- the new hardware must be modular in order to simplify maintenance and future upgrades;
- the migration from the present to the new controls must be seamless and allow for a gradual upgrade;
- the local controller must be able to operate even if the connection with the rest of the control system is incidentally lost or deliberately broken for local operation.

THE NEW PS CONTROLLER

Thanks to the capabilities of modern embedded systems and to the in-house experience [5], a new design of a PS controller fulfilling the requirements mentioned above has been carried out. The core of this device, called NewPSC (New Power Supply Controller, see Fig. 4), is the BeagleBone (BB), a compact, cheap and powerful card able to replace the VME CPU board currently used in each EIU [6,7].

In order to replace also the other analog/digital I/O VME boards, a mixed mode carrier card, called BBC (BeagleBone Carrier), has been designed.
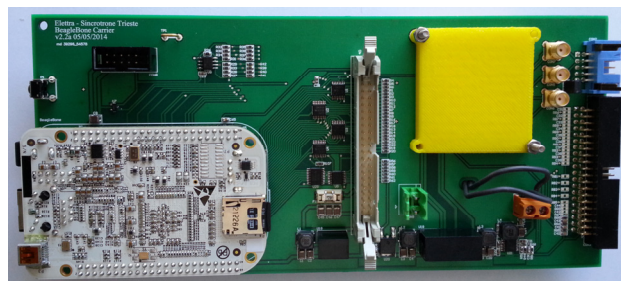

Figure 4: BBC board plus BB (NewPSC).

The BBC includes a 24-bit $\Delta\Sigma$ ADC (ADS1271) that measures the output current of the PS, and a 20-bit DAC (AD5791) that sets the voltage reference signal (0-10 V range) of the analog regulation loop [8]. The ADC, the DAC and their analog ancillary circuits are shielded and thermo-stabilized; they are located under the yellow cover shown in Fig. 4 (top right). The BBC also implements 20 digital I/O lines used for control and diagnostics tasks. A local operator panel based on a 4.3" touch screen allows performing local operations without the control system.

PS LOCAL ELECTRONICS

The original power converters, made by OCEM (an Italian power electronics company), were designed on specific custom requirements (see, e.g. [9]). The OCEM

PS local electronics uses a modular approach. Several cards (interlock, control, regulation, etc.) communicate each other via a backplane. A limitation of the actual configuration is that only the logical sum of interlocks and alarms is forwarded to the EIU, not allowing a complete remote diagnostic of the working status of the PS. For this reason, a subset of the OCEM PS local electronic boards will be replaced by an in-house designed digital I/O module, called ORC (OCEM Replacement Cards), that will forward the full set of interlock and alarm signals to the NewPSC board. Additionally, the ORCs will allow resetting the BB without affecting the operation of the PS (warm reset). This new design (BBC with new control and interlock boards) will also allow in the future a possible upgrade of the OCEM current regulation board keeping the already mounted boards unchanged.

SR OPERATION OF THE NEWPSC

After a preliminary laboratory validation test, the first prototype of the NewPSC was put in service in parasitic mode. For practical reasons (accessibility, troubleshooting and roll back), a quadrupole magnet power supply (named PSQ2_S5) was selected, and the most important signals present at the PS-EIU interface (both analog and digital) were shared with the NewPSC operating as a simple logger. This test phase continued for a full machine shift (about 30 days), during which the embedded TANGO [10] server running inside the BB and the electrical performance (both analog and digital) of the BBC were evaluated in a real operation environment. Thanks to the good results achieved during the parasitic phase, the control of PSQ2_S5 was then moved from the EIU to the NewPSC that, since January 2014, has been continuously running fine without any interruption. The complete replacement of the dipole, quadrupole and sextupole magnet power supply controllers, for a total of 42 NewPSC and ORC boards, is the next step. Because of this also the second level of communication based on the MIL-1553 fieldbus will be removed.

CONCLUSION

The experience made with the NewPSC in the Elettra control system shows that a seamless replacement of the old LPC/EIU control system, as well as the upgrade of the local electronics of the power supplies, are feasible. Some bugs, both in hardware and software, were discovered and fixed, and the final version of the BBC is now production grade, ready for the upgrade phase.

ACKNOWLEDGMENT

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