POWER CONVERTERS FOR ALBA BOOSTER

M.Pont, R.Petrocelli, D.Alloza, D.Yépez CELLS, Cerdanyola del Vallès, Spain,
M.Teixidó, G.Gross, R.Camell, CITCEA-UPC, Barcelona Spain

Abstract

ALBA is a 3 GeV third generation synchrotron light source under completion in Spain. The injection system is composed of a 100 MeV Linac as pre-injector followed by a full energy booster synchrotron. The booster requires AC power converters (PC) operating at 3.125 Hz with a sinusoidal-like current waveform. All converters are switched mode with full digital regulation and a common control interface. The design specifications have been demonstrated.

INTRODUCTION

The ALBA Booster, with 249.6 m of circumference is housed on the same tunnel as the Storage Ring and with a designed emittance of 9 nm·rad is the booster with the smallest emittance worldwide [1].

The Booster will operate at 3.125 Hz and accelerates electrons form 100 MeV to 3 GeV. To achieve this acceleration the PCs are required to produce a sinusoidal-like wave current with high repeatability.

The ALBA Booster power converters consist of 2 dipole PCs, 4 quadrupole PCs, 2 sextupole PCs and 72 correctors PCs. All PCs have been provided by BRUKER Biospin (France).

BOOSTER DIPOLES POWER CONVERTERS

There are a total of 40 dipole magnets on the Booster, each of them equipped with separate upper and lower coils. In order to stay inside Low Voltage Standard (REBT/2002) the dipole load has been split in 2 alternate lower-upper coils circuits in series, as shown in figure 1 making up a final load of 710 mOhm and 200 mH for each PC.

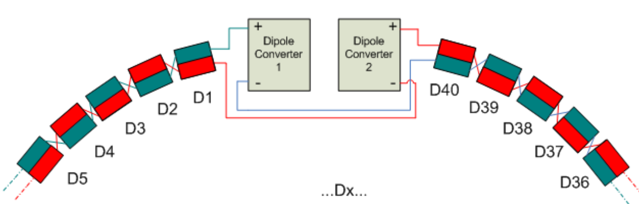

Figure 1: Cabling of dipoles magnets and converters.

The specifications of the dipole PC are shown in table 1 and the topology in figure 2.

Each dipole PC consists of two identical modules connected in series. Each module has a rectifier, an input filter, a buck converter with its filter and two 2-Quadrants converters with its filters. Afterwards, there is a common output filter before the load.

Table 1: Specification of Dipole Converters

Nr of PC	2
Irated peak [A]	±750
Vrated peak [V]	±1000
Resolution [ppm]	5
Stability 100s - 8h [ppm]	±15
Reproducibility [ppm]	±50

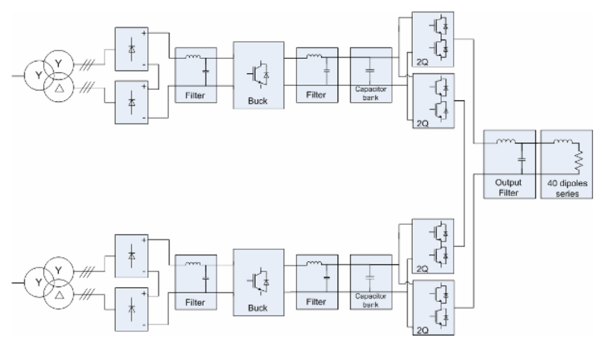

Figure 2: Dipole PC topology.

The buck module switches at 12.5 kHz and presents a constant load to the capacitor bank to reduce voltage fluctuations.

The two 2-Quadrants, connected in parallel, can be seen in fact, as one 4-Quadrant. They also switch at 12.5 kHz. The output filter, together with the output filters on each branch, provides a reduction of the current ripple and is tuned with a cut-off frequency adapted to the load.

The power converters are water cooled with 40 l/min. with and inlet pressure equal to 10 bars.

BOOSTER QUADRUPOLES POWER CONVERTERS

A total of 60 quadrupoles magnets, divided in four families are needed to run the Booster. Two families are exactly the same therefore there are only three different PCs, as indicated in table 2. Also for the quadrupoles, a modular structure has been applied, with quadrupole PC's QS180 and QS340 having only one module and QC340 having two identical modules connected in series. The topology is shown in figure 3.

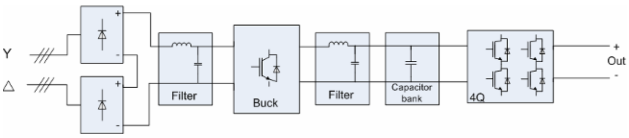

Figure 3: Quadrupole converter topology.

Table 2: Specifications of Quadrupoles Converters

Type of PC	QS180	QS340	QC340
Nr of PCs	2	1	1
Load R [mOhm]	440	610	2360
Load L [mH]	27.2	48	216
Irated peak [A]	±180	±180	±180
Vrated peak [V]	±120	±200	±750
Resolution [ppm]	5	5	5
Stability 100s 8h [ppm]	±15	±15	±15
Reproducibility [ppm]	±50	±50	±50

Buck modules as well as 4Q modules use exactly the same hardware for the four quadrupoles power supplies. In this way operation is simplified and spare parts are reduced.

BOOSTER SEXTUPOLE POWER CONVERTERS

The two sextupole PCs are based on a standard design from BRUKER: BSMPS BIP 2. This design consists of a twelve pulse rectifier fed from a 50 Hz transformer; a filter, a capacitor bank and a 4Quadrants converter. The bipolar ouput is rated at ±8 A and ±70 V. The controller is the same as used for dipoles and quadrupoles.

BOOSTER CORRECTOR POWER CONVERTERS

The 72 corrector magnets PCs are rated at ±6 A and ±12 V and their topology includes a buck converter, capacitor bank and a 4-Quadrant regulator. The corrector PCs have been used in dc mode during the Booster pre-commissioning but having the same controller as the rest of the PCs they could also be ramped in case it is required.

CONTROL ARCHITECTURE

Each buck converter and each 4Q converter has its own control board. The control board is the same for all booster power converters and is based on a 32-bit fixed point DSP, 24-bit analog to digital converters and two digital-to-analog converters to generate high resolution PWM. A CAN-bus connects all regulation units in a cabinet with a CAN to ETHERNET gateway board communicated with the TANGO control system.

In the buck converters there is an inner current control loop and an outer voltage control loop. In the 4Q converters the inner control loop is for the output voltage, and the outer one for the magnet current.

The converters which have two modules in series (Dipole and QC340 quadrupole) use a master-slave control for the output current. So each 4Q have its own inner voltage control loop, but there is only one common current control loop.

All control loops use PID controller for regulation and are executed at the switching frequency (12.5 kHz for Dipoles, quadrupoles and sextupoles and 25 kHz for the correctors).

The PCs can function in DC-mode or in sinusoidal biased wave-mode (AC-mode), being the second one the normal functioning mode. In wave-mode, a waveform generated elsewhere is downloaded to the PC via Ethernet. This waveform is then reproduced on each trigger. This is used not only for normal ramping of the booster, but also for occasional demagnetisation of the magnets through special waveforms.

PERFORMANCE

DC Mode Tests

All the Booster power converters have been subjected to the following DC tests: warm-up, stability, linearity, resolution, reproducibility, output ripple current and input Power Factor measurement.

Shown in figure 4 are the results of the resolution test for the QS180(2) quadrupole. These indicate that the 5 ppm resolution has been achieved.

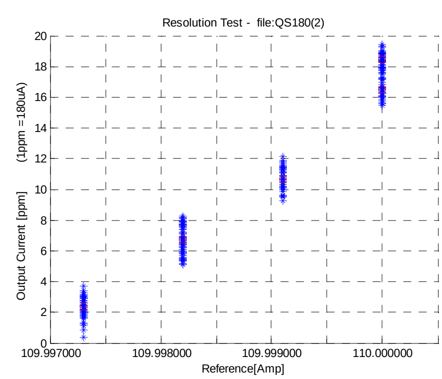

Figure 4: Resolution test results.

The 110.000A set point was sent twice in order to observe the repeatability of the power supply. The 2 outputs are reproduced within 2ppm.

AC Mode Tests

In AC mode the following tests have been performed: Reference tracking, transfer function and bandwidth for each type of PC and efficiency at full power. Especially important has been the measure of the tracking between the dipole and the quadrupole PCs.

Tracking Acquisition

The tracking is measured by specific DCCTs Ultrastab 867 from Danfysik installed on each PC whose output is connected to a 4 channels DAQ ADLINK PXI-2010 running under Matlab. The DAQ ADLINK has 14 bits of resolution, but by over sampling we have been able to achieve the desired resolution. There are 6 DCCT's (for dipoles and quadrupoles) and 2 such DAQs.

Plotted in figure 5 is the normalised tracking error (NTE) between both dipoles, which is defined as:

$$NTE = \frac{I_{dip-1}(t) - I_{dip-2}(t)}{I_{dip-1}(t)}$$

The output currents track each other within 0.1% in most of the cycle. The largest deviations are observed at the lowest currents.

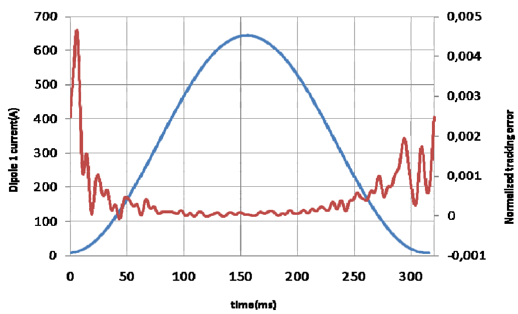

Figure 5: Output current for dipole-1 and normalised tracking error between dipole-1 and dipole-2.

Tracking Quadrupole Versus Dipole

To test the tracking between dipole and quadrupoles, the sinusoidal waveform sent to the quadrupole has been a multiple of the current sent to the dipole. In this case the normalised tracking error has been defined as:

$$NTE = \frac{I_{dip-1}(t) - I_{quad}(t)}{I_{dip-1}(t)}$$

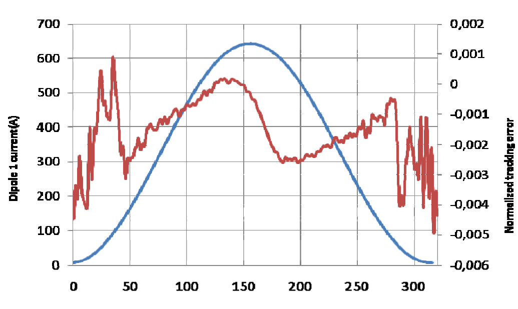

Figure 6: Dipole-1 versus quadrupole QH2 tracking.

The results indicate a tracking error inside 0.4%. Similar results have been obtained for the other quadrupoles.

Determination of Bode Diagram

In order to obtain the Bode diagram of the power converter a step function has been sent to each PC. The current response to this step function is transformed into the frequency domain by using a FFT in order to obtain the Bode diagrams of each PC. The results on dipole-1 PC are shown in figure 7.

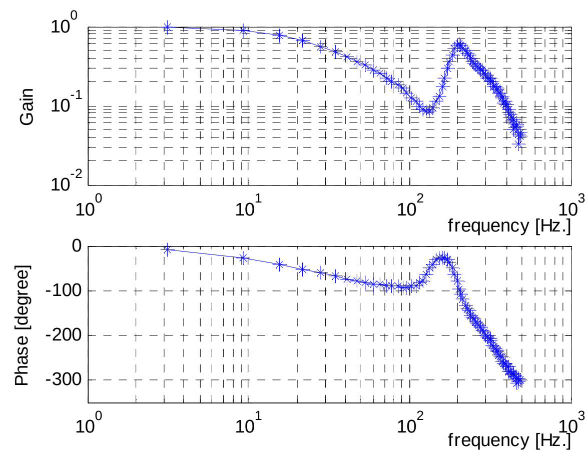

Figure 7: Bode diagram of dipole-1 PC.

This test is made at low current in order to avoid saturation of PI loops and operational amplifiers among other components. The Bode diagram has been used to exactly synchronise all power converters with CELLS main injection trigger. All of the control parameters of the PC's can be remotely and locally adjusted.

CONCLUSIONS

The topology and control of the different PCs for the ALBA Booster have been presented.

During the Booster pre-commissioning phase [2], a ramp from 100MeV to 3GeV with a frequency of 3.125Hz has been achieved.

REFERENCES

[1] G.Benedetti, D.Einfeld, Z.Martí, M.Muñoz and M.Pont, "Optics for the ALBA booster synchrotron", EPAC'08 Genoa, 2008.

[2] M.Pont, "Booster of the ALBA synchrotron light source: Pre-commissioning experiences", these proceedings