Evaluation and testing of advanced low-voltage power supplies

B. Allongue

CERN, 1211 Geneva 23, Switzerland

bruno.allongue@cern.ch

Abstract

A distinguishing feature of the LHC detectors is the enormous number of front end electronics channels in all the sub-detectors. Low voltage power supply systems in the range of multi kilowatts are required to bias such electronics. These power supplies will be located in the cavern close to the detector where stray magnetic field and radiation are present. The main advantage of this topology is the reduction of the length cable needed to carry power to the electronics.

This paper describes results on electrical and environmental tests performed on sample equipment. Descriptions of the objects and methods of tests are given.

I. INTRODUCTION

Several of the sub-detectors in the LHC experiments will have a low voltage distribution for the front-end electronics based on independent multi-channel low voltage power supplies. The overall concept is to distribute DC at high or low voltage to power converters located in the cavern close to the detector, and to transform the DC voltage (400V or 48V) to the required low voltages (between 2V to 8V). This topology reduces the total cross-section of the distribution cables, but the converters have to operate reliably in a hostile environment with significant radiation and stray magnetic fields.

In collaboration with a number of the LHC experiments' sub-detectors, electrical and environmental specifications were established in order to launch a market survey and call for tender by CERN to identify potential suppliers. Eventually W-IE-NE-R Plein & Baus Elektronik - "Wiener" (Germany) and CAEN SpA (Italy) were selected.

To validate the operation of candidate low voltage power supplies, tests were performed on one sample of each item. Verification of the compliance to the electrical specifications, as well as the tolerance to magnetic fields, was made at CERN, whereas radiation tests were performed in several institutes outside CERN.

In this paper the test methodology and results are described, including electrical tests (input and output parameters, efficiency, regulation, ripple and protection etc.), EMC tests (e.g. power factor, harmonic rejection), magnetic field tests, and radiation tests.

II. DESCRIPTION

A. Wiener MARATON

The Wiener MARATON (**MA**gnetism and **RA**diation **TO**lerant **N**ew) is a floating multi-channel high density power supply system consisting of three parts (see Figure 1):

- The AC/DC/PFC which converts the input AC voltage into high DC voltage. The box format is 4U x 14TE x 450mm and can be inserted in a 19''assembly for hosting up to 6 units. It is not tolerant to radiation and magnetic field and must be located in a normal environment. The nominal output power is 3.9kW and the nominal output voltage is 385VDC. The unit also provides active power factor correction.
- The RCM (Remote Control Module) for the control and monitoring is also not tolerant to radiation and magnetic field and has to be located in safe area. It is a 6U VME board form factor, 160mm, 4TE. It can control and monitor up to 12 channels.
- The power box which houses up to 12 DC-DC converter modules supplying the DC output voltage can be located in the hostile environment since it is tolerant to radiation (140Gy over 10 years), and magnetic field (120mT). The format of the box is 3U x 19'' x 325mm.

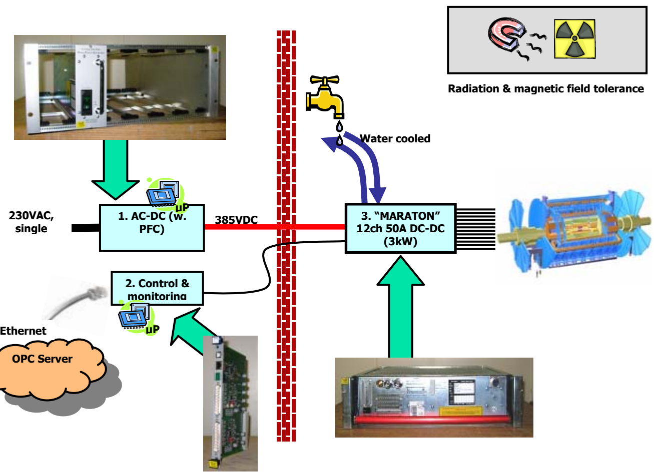

Figure 1: Wiener implementation

B. CAEN EASY

The CAEN EASY (**E**mbedded **A**ssembly **SY**stem) is a low-voltage voltage power supply system designed as an extension to CAEN's existing SY1527 high and low-voltage system, with tolerance to radiation and magnetic fields.

The EASY system consists of four main parts (see Figure 2):

- A radiation and magnetic field tolerant three-phase AC to 48VDC converter providing a 4KW power source for the EASY system.
- An input filter required to reduce harmonic emissions and which acts as a passive power factor corrector. It is not magnetic field tolerant so it must be installed in a safe area.
- Control and monitoring is provided by the SY1527 or SY2527 controller, which also have to be located in a safe environment since they are not tolerant to either magnetic field or radiation.
- A range of radiation and magnetic field tolerant DC-DC converter modules housed in a 6U crate.

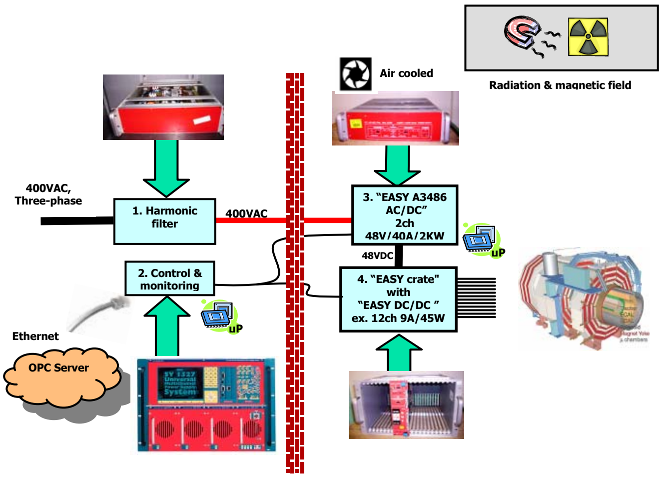

Figure 2: CAEN EASY implementation

III. Tests and Measurements

A. Electrical tests

These tests consisted of measuring the following electrical parameters for each output channel as well as the overall power supply, functioning in nominal conditions:

- Regulation
  - Static
  - Dynamic
- Efficiency
- Noise and ripple
- Turn ON and OFF characteristics
- Protections
  - Over-current
  - Over-voltage
- Stability
- EMC (Harmonic emissions)

1) Test set-up

The input parameters (i.e. voltage, current and power) are measured by means of an Infratek 603A power analyzer. An electronic load, HP 6050A, was used to sink current from the power supply and to perform current step for dynamic response. The output parameters (i.e. voltage and ripple, etc.) were acquired with a Keithley Digital Voltmeter and a Philips oscilloscope. Figure 3 shows the test-set-up.

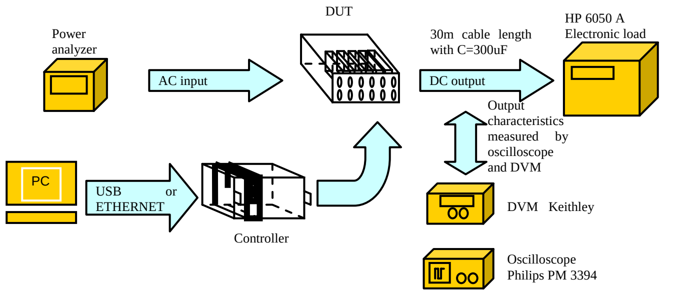

Figure 3: Test set up

2) Test results (Wiener)

The electrical parameters were found to be all within the technical specification with the exception of the ripple which was measured as 15mVpp instead of 10mVpp, but which was considered acceptable (see Table 1).

Table 1:Electrical test results (Wiener MARATON)

Criterions	Specification	Measurement
Static regulation	0.5%	0.034%
Dynamic regulation	10%	8%
Efficiency	70%	75%
Ripple	≤10mVpp	15mVpp
Turn ON	>50ms <100ms	75ms
Turn OFF	<5ms	2.5ms
Current Limit	110%	109.7%
Over-voltage	125%	124%

Table 2:Input AC parameters (Wiener MARATON)

	Phase	Units
Voltage RMS	228.9	V
Current RMS	21.4	A
Active power	4673.2	W
Reactive power	320.8	VAR
Power Factor	0.997	-
Frequency	50.02	Hz
THDi	10^{-5}	-

3) Harmonic emissions(Wiener)

The Wiener MARATON power supply was measured to be compliant to the EMC standard 61000-3-2 from the 1[st] to the 50[th] harmonic.

4) Test results (CAEN EASY)

Some functions were found not to be compliant to the technical specification (see Table 3).

Table 3:Electrical test results (CAEN EASY)

Criteria	Specification	Measurement
Static regulation	0.5%	100% in specification
Dynamic regulation	10%	100% in specification
Efficiency	70%	DC/DC: 65% AC/DC: 88% Overall: 57%
Ripple	≤5mVpp	18mVpp
Turn ON	>50ms <100ms	100% in specification
Turn OFF	<5ms	150ms
Current Limit	110%	100% in specification
Over-voltage	125%	No crowbar

5) *Harmonic emissions(CAEN without harmonic filter)*

The CAEN EASY system, without harmonic filter, was not compliant to the EMC standard for harmonic current emissions 61000-3-2 for harmonic number 5, 7, 11, 13, 17, 19, 23, 25, 29, 31, 35. The Power Factor: 0.73 and the THDi: 0.65 were also measured to be out of specification (see Table 4).

Table 4:Input AC parameters (CAEN EASY)

	Phase 1	Phase 2	Phase 3	Units
Voltage RMS	230.1	230.2	230.1	V
Current RMS	7.65	8.02	7.65	A
Active power	1290	1301	1270	W
Reactive power	1200	1250	1200	VAR
Power Factor	0.73	0.73	0.73	-
Frequency	50	50	50	Hz
THDi	0.65	0.66	0.65	-

6) *Harmonic emissions (CAEN with harmonic filter)*

To improve the AC characteristics, a harmonic filter was required in order for the EASY system to conform to the EMC standard for harmonic current emissions 61000-3-2 from the 1^{st} to the 50^{th} harmonic. The Power Factor of 0.97 and the THDi: 0.17 were brought within specification (see Table 5).

Table 5:Input AC parameters (CAEN EASY)

	Phase 1	Phase 2	Phase 3	Units
Voltage RMS	229.2	230.2	230.1	V
Current RMS	6.18	6.13	5.93	A
Active power	1360	1350	1330	W
Reactive power	2950	2590	2670	VAR
Power Factor	0.98	0.98	0.97	-
Frequency	50	50	50	Hz
THDi	0.18	0.19	0.19	-

B. Environmental tests

Based on the requirements of the LHC experiments, two environmental specifications were established (see Tables 6 and 7).

Table 6: Magnetic field and radiation tolerance for specification A

Category	Mag. field (mT)	TID (Gy) (10 yrs)	N/cm^2 1Mev (10 yrs)	P/cm^2 >20Mev (10 yrs)
Normal environment	<5	$<5\ 10^{-2}$	-	-
Low magnetic field, low radiation ***ALICE***	<30	$<1\ 10^{-1}$	10^{10}	$2\ 10^{9}$
Low magnetic field, high radiation ***LHCb***	<30	140	10^{12}	$2\ 10^{11}$
High magnetic field, high level radiation ***ATLAS-TRT***	<120	140	10^{12}	$2\ 10^{11}$

Table 7: Magnetic field and radiation tolerance for specification B

Category	Magnetic field (mT)	TID (Gy)	Neutrons N/cm^2 1Mev	Protons P/cm^2 >20Mev
CMS experiment	180[1]	4	10^{11}	10^{10}

1) *Magnetic field tolerance tests*

These tests consist of measuring the tolerance of the power modules in magnetic field environment working in nominal output power conditions in all axes. They were performed at CERN using magnets with different dimensions.

The PH/ESS magnet was used for component tests, since its aperture is only 15cm. The maximum magnetic field is 1.8kGauss. See Figure 4.

Figure 4: PH/ESS magnet

To test complete systems, a magnet with 50cm aperture was necessary, and the CERN MNP22 magnet was used, see Figures 5 and 6.

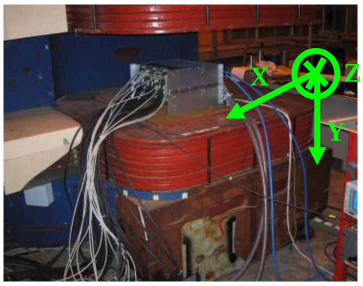

Figure 5: Wiener MARATON system

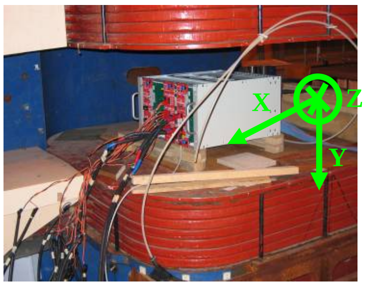

Figure 6: CAEN EASY system

2) *Magnetic field tolerance test results*

<u>Wiener MARATON</u>

The approach taken by Wiener to magnetic field tolerance was to start with one of their standard low voltage power

[1] The magnetic field tolerance requirement for CMS was relaxed to 120mT after a new simulation of the stray magnetic field.

supply products and to make the minimum modifications necessary to make acceptable for LHC environment. The changes included soft iron screening of the magnetic components, such as transformers and inductors and, following tests, a judicious selection of components for radiation tolerance.

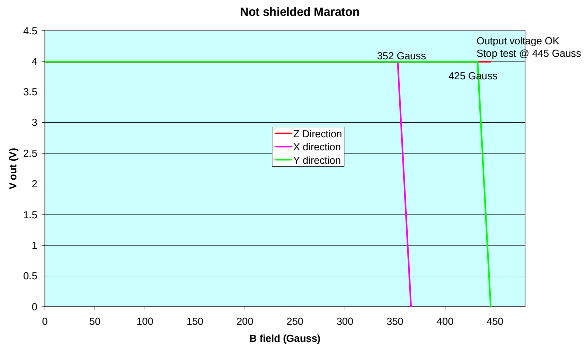

Figure 7: Magnetic field test for non-shielded MARATON

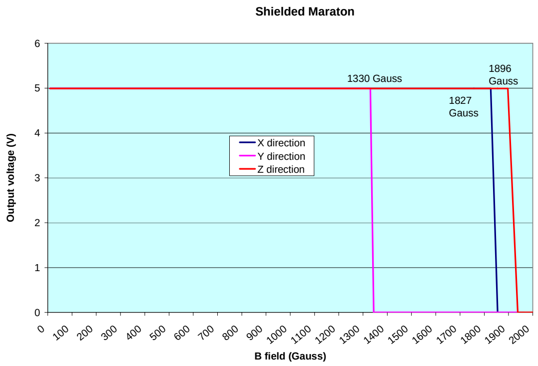

Figure 8: Magnetic field test for shielded MARATON

Both Wiener MARATON power supply topologies, unshielded and shielded, are conformant to the technical specification A in any magnetic field direction: 30mT for the unshielded and 130mT for the shielded.

CAEN EASY

CAEN adopted a novel research strategy using transformers with high permeability able to operate in high external magnetic field

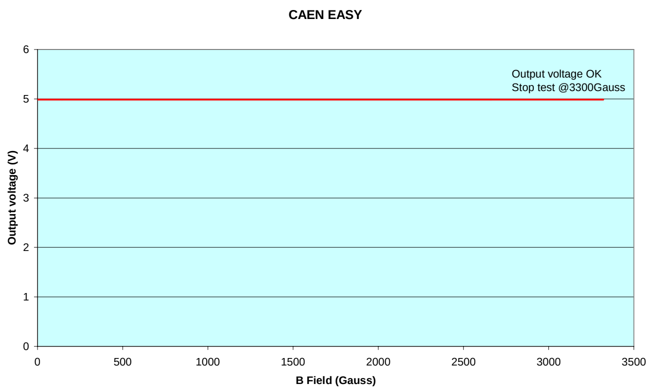

Figure 9: Magnetic field test for CAEN EASY

All the CAEN EASY equipment is compliant to both the A and B technical specifications concerning the magnetic field tolerance. Figure 9 shows the response of one EASY power module (A3009); the results obtained for all the DC-DC converters tested were found to be identical.

3) Radiation tolerance tests

These tests consisted of measuring the tolerance of the power modules to radiation working at nominal output power conditions, and were performed several facilities.

For proton tests, beams in three different locations were used. The PSI (Paul Scherrer Institute), in Switzerland and the UCL at Louvain la Neuve, in Belgium have small diameter beams (8 - 10cm), and were used to test devices at component level.. Complete systems, for which a large beam was necessary; were tested in the TSL proton beam at Uppsala in Sweden which has a diameter of 15 to 20cm (see Figure 10).

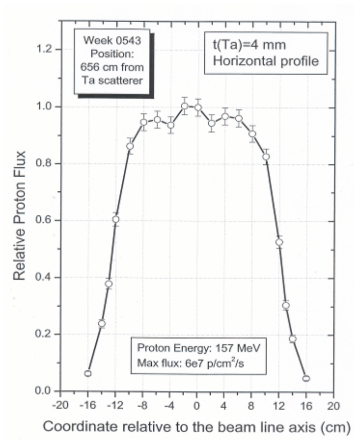

Figure 10: TSL Uppsala beam profile

For NIEL tests, the PROSPERO nuclear reactor at Valduc near Dijon in France which produces neutrons at 1Mev energy was used, and for TID tests a cobalt 60 source in Cassacia in Italy was used.

Figure 11:Uppsala protons beam

Figure 12:PSI proton beam

Figure 13:PROSPERO reactor

4) Radiation tolerance test results

Several irradiation campaigns demonstrated the weakness of various components and corrective actions were required.

In the Wiener topology, opto-couplers had to be changed because of NIEL effects. Also, due to the implementation of a Power Factor Corrector, switching transistors having a greater drain-source voltage were used, necessitating extra radiation tolerance tests.

In the CAEN topology, a low pass filter in the microprocessor reset line had to be implemented, due to the sensitivity to high energy hadrons of the existing opto-couplers. Also, other components such as amplifiers and EPROMs had to be replaced.

After several iterations, over a number of years, the tolerance of the Wiener MARATON to radiation was as shown in Figure 14.

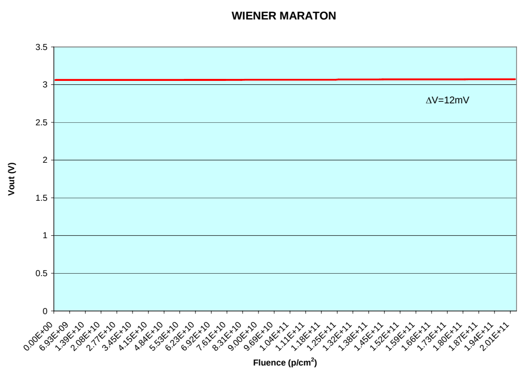

Figure 14:Radiation test for the Wiener MARATON

After modifications made on the CAEN EASY system, it behaved under radiation as shown in Figure 15.

Concerning Wiener, there no event was seen up to $2*10^{11}$ p/cm^2, 14kRad. Previous campaigns for NIEL tests were also successful. Concerning CAEN, there is one event due to the loss of communication between the controller and the EASY module. However this is acceptable since this fluence represents 10 years of operation of the experiments.

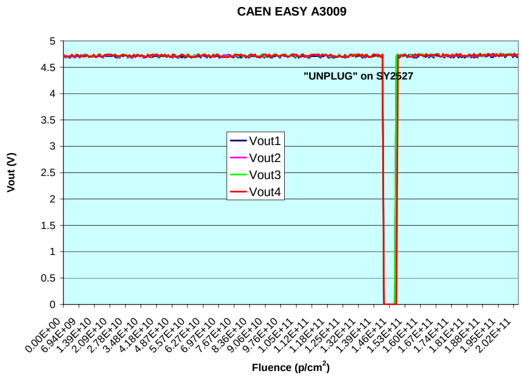

Figure 15:Radiation test for the CAEN EASY

IV. Conclusions

Some of the specified parameters had to be adapted to changes in the requirements of the detectors during the approval process. In addition, compromises were accepted to the specification where the resulting changes had limited impact on the overall performance of the power supplies. Qualified radiation and magnetic field tolerant detector power supplies are now available to the four LHC experiments from two suppliers, CAEN and Wiener.

The qualification of COTS equipment is a very long, costly and painful process. Close collaboration between users, power supply and radiation tolerance specialists at the earliest possible stage is of prime importance to minimize the time required as well as the overall cost.

V. Acknowledgements

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In addition many other colleagues from CERN, the LHC experiments and the two manufacturers concerned have made very important contributions...

VI. References

[1] Wiener MARATON user manual. http//www.wiener-d.com/
[2] CAEN EASY user manual. http://www.caen.it/
[3] Test report in preparation