Low Voltage Floating Power Supply Systems for LHC Experiments

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Abstract

A water cooled, Magnetic field and Radiation Tolerant New floating Power Supply System MARATON is described as well as special Power Supplies, for driving loads over long distance in hostile (HE) or save (SE) environment as well as for installation around the detector in HE environment.

Air cooled versions for use in low magnetic fields are available alternatively.

Easily adaptable to changing demands by modular design. Common to all are very low noise and ripple, even at highest currents.

A remote monitoring system based on CAN bus and Ethernet is given.

I. Introduction

LHC experiments require power supplies for use in either SE-Area to provide loads over long distance, in sensed- or not sensed- mode, or as systems for operation in HE-Area.

Stable operation, independent of cable length, is as important as lowest output noise and ripple. Conducted noise and RF-emission generated by the switching power supplies should be as low as generated by linear regulated supplies. In Hostile Environment power supplies have to work in magnetic fields of several 1000 Gauss and with irradiations of up to 10^{12} neutrons/cm² and TID of some krad, accumulated over ten years.

Also a sufficient remote monitoring- and control-system should be available.

This paper describes different low voltage floating power supply systems for SE- and HE-Areas.

While standard Wiener-Power supplies can work in lower magnetic fields without further provisions, for higher than 300 G B-fields special screenings for the magnetic sensitive parts inside the power box have to be foreseen.

To provide a sufficient cooling, even in higher magnetic fields where motor driven fans are not able to work, a high efficient water cooling system has been developed.

Further the insensitivity of HE power supply systems against magnetic fields have been improved. Now we can present a 20% higher immunity compared to the results described at the 9th workshop of LHC experiments [1]. The radiation hardness has been tested now with input voltages of 385VDC. This relatively high voltage permits low cross-sections of cabling between SE- rectifier and HE- power supplies and makes direct powering from 230/400VAC mains possible via simple primary rectifier with Power Factor Corrected AC input. In addition a 260VAC 3-phase-input with 400Hz is possible to reach full output performance, too.

II. Type Spectrum of available Power Supplies

The PL 5-/Pl 6- series power supplies can be divided into

1. Suitable for SE only (PL 500 /PL 6-)
2. Suitable for moderate HE with low B-field and low radiation (PL 5-WC / PL 6-WC)
3. Suitable for HE with up to 1500G B-field and full LHC radiation spectrum / dose (MARATON, MAgnetism and RAdiation TOlerant New Power Supply System)

1. SE- Area Types

PL 500 F has been designed to provide external loads with high power consumption over long distances in a sensed mode.

PL 6-- F is suitable for short sensed wiring to the loads or in non-sensed mode for long distance wiring.

All voltages, currents, temperatures and output power are controlled by the internal micro processor. Illegal modes as well as failures will be automatically detected.

A fast sense circuit and for PL 500, a delayed remote-sense compensation guarantee continuous and stable operation, even with long inductive wiring to the loads and high voltage drops.

The power boxes are designed as plug-in units, to be housed in a special 19” assembly (Power Bin) for rack mounting

An alphanumeric data monitor with diagnostic and programming capability can be integrated optionally.

These power supplies can be programmed and monitored remotely via, CAN bus and TCP/IP (F8: CAN bus only).

The PL5/6 features 8 or 12 (F8-F12) independent potential free DC outputs with up to 3kW output power (at 230VAC mains) in a 3U box with the following characteristics:

- Trip Off for individual channel, group or all
- Trip Off with fast output discharge
- Programmable voltage ramps,
- Programmable group behavior (F12)
- Programmable warning and trip levels
- Extremely low noise and low ripple
- Wide range sinusoidal mains input
- CAN bus and TCP/IP Ethernet (WWW) Interface
- COM- Port for easy configuration

Optional:

- Individual Interlock input
- Intelligent alphanumeric monitoring

Figure 1: Bottom view of PL500F12, open box with 6 dual modules

2. Moderate HE- Area Types

All above listed features are also given with the PL 5/6-WC, which are the water cooled versions. While the standard versions, cooled by internal fans, can be used up to a maximum B-field of 130G, the water-cooled

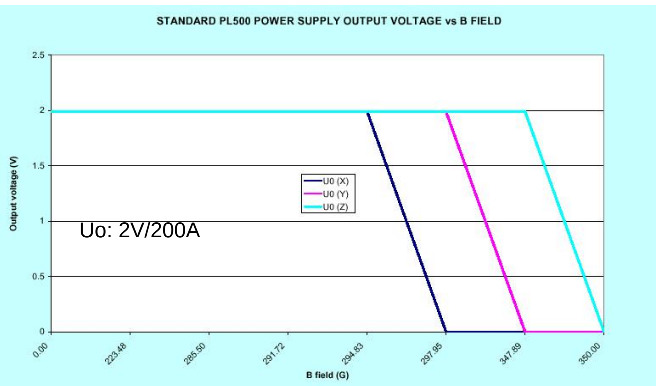


Figure 2: B-field action related dependence of PL500 output [2]

power supplies allow operation up to 290-300G [2] without additional shielding of magnetic articles.

Figure 3: Water cooled PL500 F8, 5 single and 1 dual module

Equipped with non power-factor-corrected mains input for 230VAC+/-10% or –for full power performance- with 385VDC operation the PL500F8 can work in moderate radiation ambient up to 3krad.

3. HE Area Types

Based on the water cooled PL 5/6- series the MARATON power supplies offer a long run approved technology. Eight channel versions (F8) can work in limited radiation ambient up to 3krad and B-fields of 1280-1500 G with internal CAN bus interface.

With external monitoring module both F8 and F12 fulfill the LHC requirements of radiation exposure entirely.

The radiation tests of PL 500 and MARATON started already in 2000 with first installations at the TCC2 facility at CERN followed by recurrent tests at Lovain-la-Neuve and Paul-Scherrer-Institut.

A quasi-redundant principle of power conversion is realized with two transistors, which are sharing the operating voltage whereas each is able to handle the power

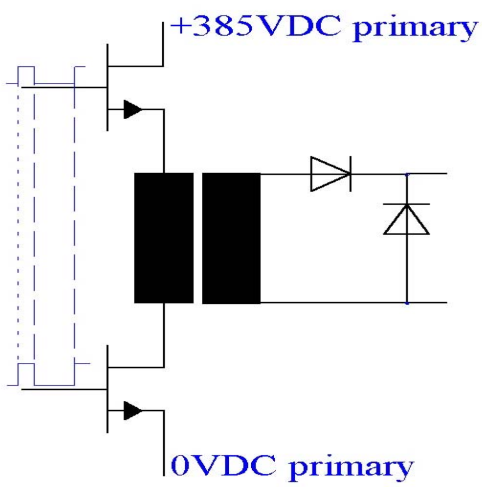


Figure 4: Two-Transistor-Converter principle

management alone (even at full load). This makes the circuit extremely resistive against single event effects.

III. MARATON IRRADIATION TESTS

The first tests were done with standard PL500 electronics, using 400V transistors. The power modules passed the test but 400V-transistors showed single event effects under a separate transistor test.

Final tests with 385VDC operation voltage were performed with 900V transistors installed instead. These transistors give inherently sufficient radiation hardness corresponding to the expected radiation level of LHC. The following table shows the different test steps, beginning in 2000 until today:

Facility	Mains Input MNE Module MARATON AC/DC Input	2-7V/100A single MEH Module	+/-5V/30A (2-7V) Dual MDH Module MARATON MDM 2x300W 2x60Apk	+/-15V Aux-Power MUH Module MARATON MORT for ext. Monitor-board	Controller Board CANbus Micro Processor
A	passed	passed	passed	fails	passed, excl. CAN
B	passed	passed	passed	New Module passed	fails after 417Gy
C	New Module SEE 4.0E+10 p/cm	passed	passed	not tested	not tested
D	New Module passed	not tested	not tested	passed	**SEE 3,1krad 3x Power Cycle for passing**
E	MARATON Input 385VDC **passed**	not tested	MARATON Input 385VDC passed	MARATON Input 385VDC passed	

A	2000	TCC2	722Gy	7.99E+12 n/cm²
B	2002	TCC2	417Gy	7.69E+12 n/cm²
C	2002	Louvain SEE		1.0E+11 p/cm²
D	2002	PSI SEE	14krad	1.0E+11 p/cm²
E	2004	Louvain SEE		3,0E+12 p/cm²

All tests under responsibility of Cern Member

Figure 5: Irradiation results 2000-2004

MARATON modules MDM are dual types with fully screened magnetic sensitive parts (power-transformer, chokes, gate-pulse-transformer) and equipped with a heat exchanger. For SEE test a heat sink and forced air cooling was used. The output voltage at the beginning was adjusted to 3,00V, with 50A current. The test starts at 00:40:44 am and was finished at 02:41:55 am. A second module test started at 2:52:08 am and ended at 4:50:54 with a total dose of 3,0E+12 p/cm² for both with 60MeV Proton Energy. The sample clock for voltage- and current- measurement was 1/s. No SEU effects could be detected but the output voltages increased to the end of the test time to 3.01V for three of the four tested channels. One showed 3,02V.

IV. MARATON B-FIELD- TESTS

All following described magnetic field tests were carried out at CERN [2] at the CERN Magnet Facility in hall 887, EHNI, Prevessin.

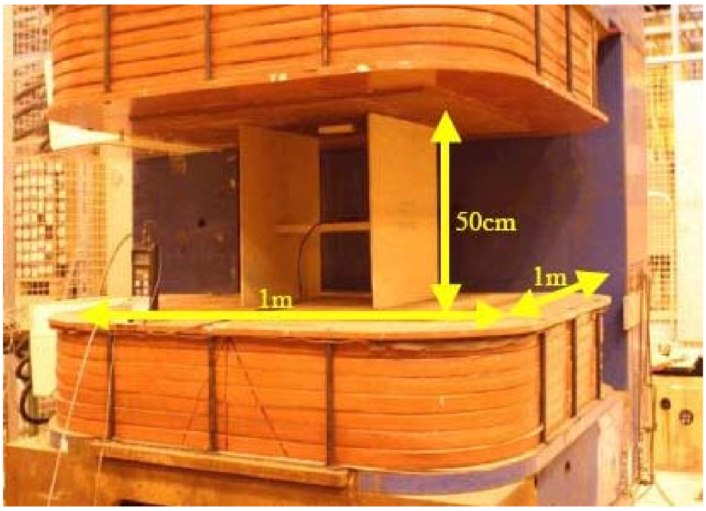


Figure 6: Magnet

The tested MARATON system was configured according to estimated LHCb power requirements:

Uo:	5V	100A
U1:	5V	100A
U2:	3,3V	200A
U3:	48V	12A
U4	5V	100A

The output currents of U_0-U_4 were realized by parallel operation of two or more outputs of the dual MDM modules. A total of 6 modules was installed.

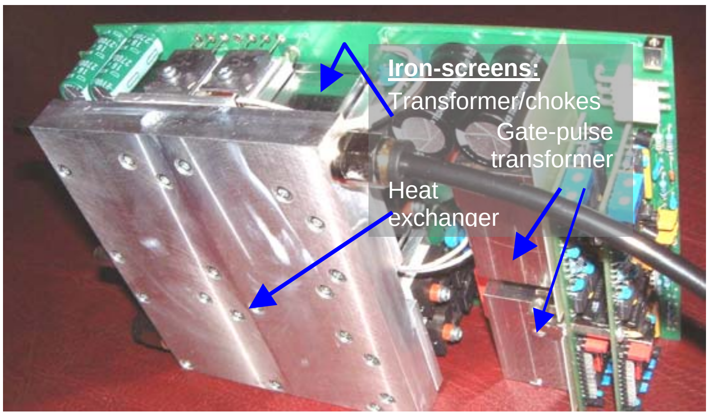


Figure 7: MARATON MDM-dual module with 3krad regulator boards

The shielding of the magnetic sensitive parts was further improved. Because of the very efficient cooling system the power transformer size could be minimized which resulted in an increasing B-field tolerance. In addition the module weight was reduced even though the shielding cover got an increased wall thickness.

This test report considers mainly the 600W MDM dual module with 50A (60A peak) output per channel which gives the best power to cost relation. A reduced power per channel may lead to still smaller ferrite cores with further advanced B-field tolerance by enhancing the shielding material.

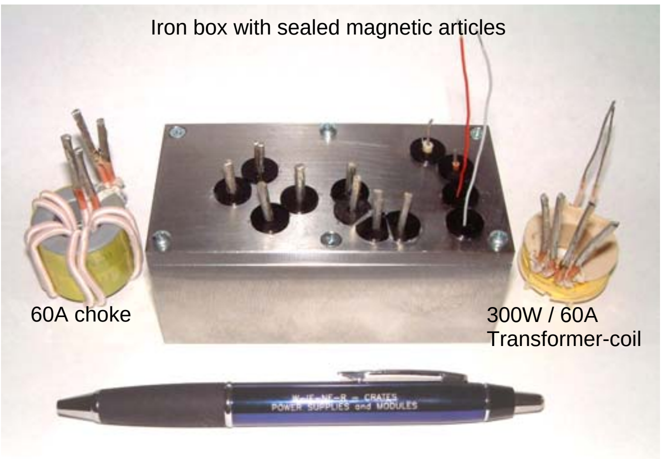


Figure 8: Iron box with transformer and choke (one channel)

The magnetic field directions were determined for the given test in such a way that X and Z are on horizontal level, relating to normal 19” rack mounting position of a standard power bin. In case a hinged power bin will be used, or the “three-fold-upright” power bin, the final fitting position turns around the X-axis by 90°. These facts could be helpful in some cases to optimize the position of MARATON inside the B-field because magnetic interaction to the three axis is different.

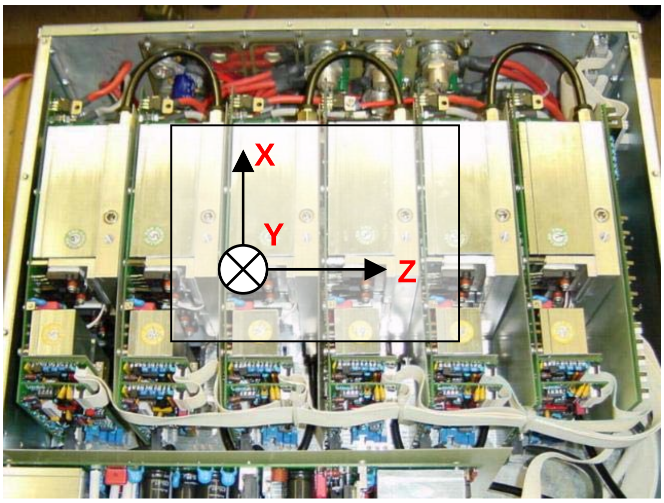


Figure 9: MARATON DUT: Magnet field directions

The test set up consists of Primary Rectifier with PFC input which provides 385VDC to the MARATON. Outputs are charged with electronic loads. The following diagrams show the results depending on various B-field flux.

Figure 10: B-field effects X direction, Knee point at 1567,5 G [2]

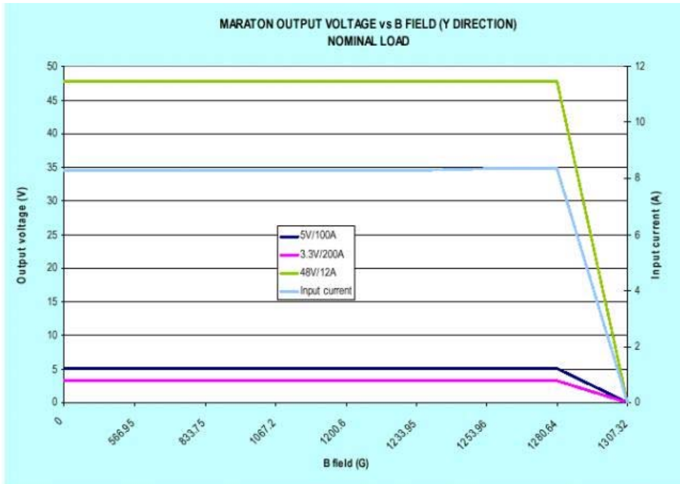


Figure 11: B-field effects Y direction, Knee point at 1280,64 G [2]

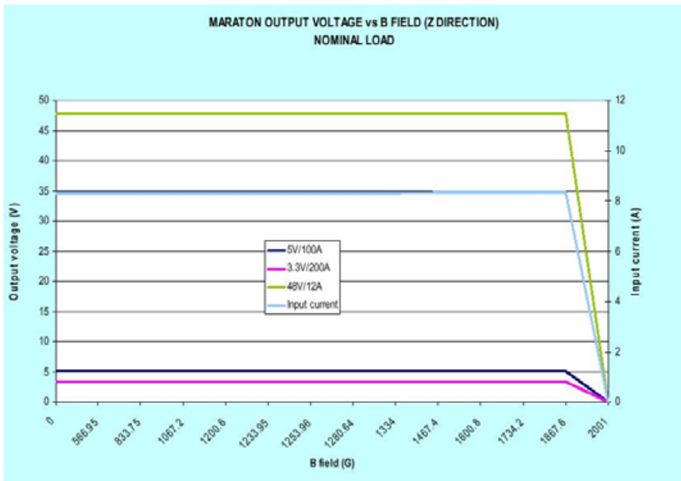


Figure 11: B-field effects Z direction, Knee point at 1867,6 G [2]

The input current shows only a very little increase when the B-field rise to the knee point of 0,6% [2]. Therefore the efficiency remains nearly on the same level as in SE use. When the B-field exceed the knee point until the ferrite saturation point the outputs runs under current limiting mode with increasing ripple, resulting from the 300kHz switching frequency. During this status the input current is also reduced by the fast “pulse by pulse” current limiting. No further energy will be transformed to the output.

The MARATON power supply worked within specifications up to 1280 Gauss in the worst direction for magnetic fields [2].

V. NOISE AND RIPPLE

PL5/6 series and MARATON are designed in the well-established “cavity technology” which prevents conducting of high energetic RF- noise to the DC-outputs as well as to the environment. Therefore these power supplies are fully in accordance with international FCC rules.

Also the effect of noise injection into long LV distribution cables by common mode (CM) and differential mode (DM) noise could cause resonant effects [3]. The cable could start to radiate RF to the ambient but otherwise it may feed an increased level of distortion to the front-end electronic.

PL5/6- and MARATON series are outfitted with very efficient EMI provisions that all LHC requirements will be fulfilled without complicated external filtering.

Output noise and ripple, measured after 0,5m wire, are less than $10mV_{pp}$ in the bandwidth range 0-20MHz, respectable 2mVrms (0-30MHz). After 10m cable length or more the remaining noise and ripple, periodic and random, is less than $5mV_{pp}$, typically < $3mV_{pp}$ and <0,5mVrms, measured in a bandwidth range of 0-300MHz. The load site has to be assembled with 330µF or more and 1µF ceramic in parallel as well as 100nF to case (both lines, + and return). To prevent coupling-in of ambient RF distortions into the long cables it is to recommend to use screened power cables. Further all measurement cables and connectors should be coaxial and the oscilloscope inputs have to be terminated with the adequate wave impedance (50 ohms commonly).

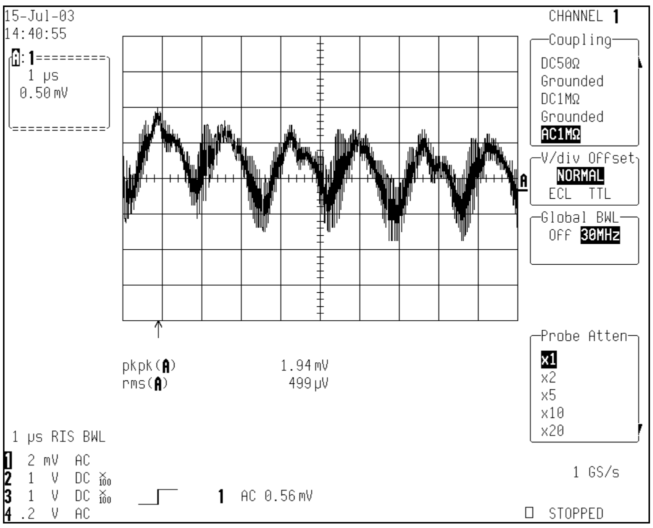


Figure12: 5V/100A with 1,94mVpp, 0-30MHz, PARD

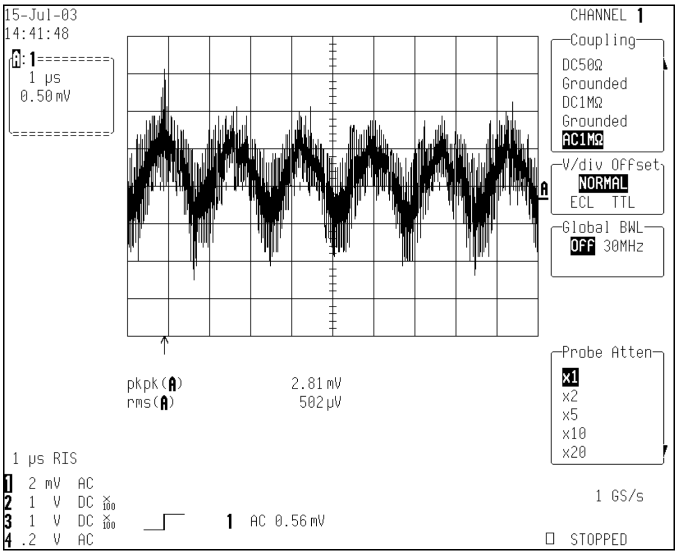
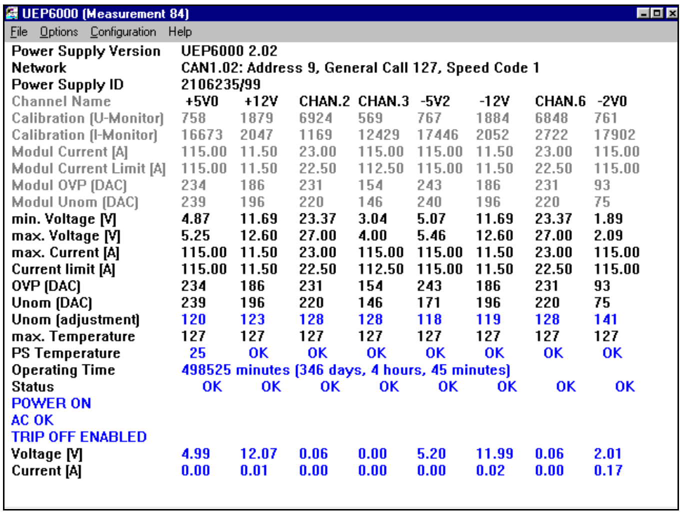


Figure 13: 5V/100A with 2,81mVpp, 0-300MHz, PARD

The 385VDC primary interconnection is EMI filtered double-sided. Neither PFC-rectifier noise nor conduction-bound noise from the power supply switching parts can cause to RF distortions.

VI. MONITORING AND CONTROL

For the SE versions CAN bus is the basic remote control and monitoring standard, even when the F8 technology is selected to provide higher output currents. The F8 can control up to 8 DC outputs. Also for moderate HE-areas the embedded CAN bus interface can be used.



UEP6000 (Measurement 84)

File Options Configuration Help

Power Supply Version	UEP6000 2.02							
Network	CAN1.02: Address 9, General Call 127, Speed Code 1							
Power Supply ID	2106235/99							
Channel Name	+5V0	+12V	CHAN.2	CHAN.3	-5V2	-12V	CHAN.6	-2V0
Calibration (U-Monitor)	758	1879	6924	569	767	1884	6848	761
Calibration (I-Monitor)	16673	2047	1169	12429	17446	2052	2722	17902
Modul Current [A]	115.00	11.50	23.00	115.00	115.00	11.50	23.00	115.00
Modul Current Limit [A]	115.00	11.50	22.50	112.50	115.00	11.50	22.50	115.00
Modul OVP (DAC)	234	186	231	154	243	186	231	93
Modul Unom (DAC)	239	196	220	146	240	196	220	75
min. Voltage [V]	4.87	11.69	23.37	3.04	5.07	11.69	23.37	1.89
max. Voltage [V]	5.25	12.60	27.00	4.00	5.46	12.60	27.00	2.09
max. Current [A]	115.00	11.50	23.00	115.00	115.00	11.50	23.00	115.00
Current limit [A]	115.00	11.50	22.50	112.50	115.00	11.50	22.50	115.00
OVP (DAC)	234	186	231	154	243	186	231	93
Unom (DAC)	239	196	220	146	171	196	220	75
Unom (adjustment)	120	123	128	128	118	119	128	141
max. Temperature	127	127	127	127	127	127	127	127
PS Temperature	25	OK	OK	OK	OK	OK	OK	OK
Operating Time	498525 minutes (346 days, 4 hours, 45 minutes)							
Status	OK	OK	OK	OK	OK	OK	OK	OK
POWER ON								
AC OK								
TRIP OFF ENABLED								
Voltage [V]	4.99	12.07	0.06	0.00	5.20	11.99	0.06	2.01
Current [A]	0.00	0.01	0.00	0.00	0.00	0.02	0.00	0.17

Figure 14: Power supply parameter display, CAN bus

The F12 version for SE- areas offers universal monitoring and control facilities, consisting of CAN bus, COM-port and TCP/IP interface. Furthermore the TCP/IP works as a Telnet in combination with the COM-port (RS232). Monitoring is easily possible via a web browser as shown in Fig. 15, which displays all voltages, currents and status information. On / off commands, etc. are password protected. For parameter programming and integration in slow control systems the SNMP protocol is used.

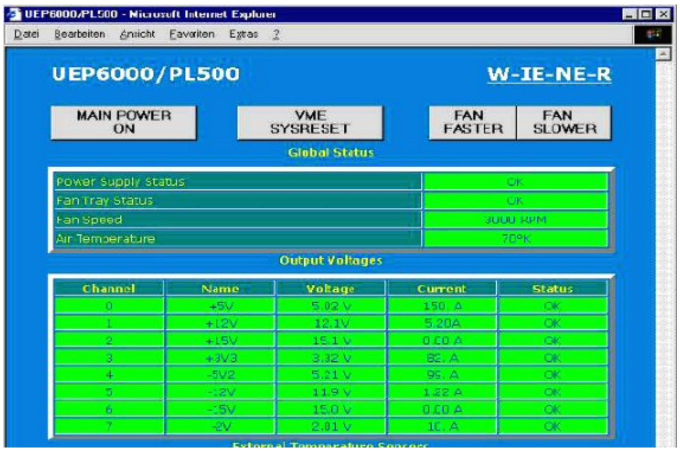


Figure 15: Power supply operation display, TCP/IP web interface

The first version of the OPC server for Wiener CAN bus slow control (for Crates) is already installed at CERN. Updates for PL5/6 and MARATON will follow soon.

For higher radiation in HE- areas MARATON features two different solutions. The internal monitoring board is foreseen only as a base for bearing mezzanine boards and for clock generation and power fail detection.

As mezzanine board comes into consideration either a radiation tolerant and redundant microprocessor board with CAN bus / TCP/IP interface or a parallel interface for a connection to external monitoring devices.

When using external monitoring less parameter are programmed or controlled. Thus it appears that the regulator boards do not need any more so much active components for processor-controlled adjustments. Consequently the concerned DAC's have been replaced by potentiometers for manual adjustment. This improves the reliability under radiation, too. As we learned during many radiation and temperature test, the final adjusted output voltages show excellent long-term stability. Re-adjustments will be rarely necessary.

With the parallel interface each sense line /output voltage is connected to the interface connector.
A combined STATUS / Switch On - line is available for each channel separately.
Signals of 6 channels are fed to one 37-pin Sub-D connector (2 fold for 12 channels)

The cable connection to the external monitoring board can be made by a 40-pin shielded, twisted-pair, halogen-free round cable (AWG26). The outer diameter of such a cable is 12 mm

Figure 16. Exemplar of a VME monitoring board for 6 channels

Monitoring boards can be based on VME standard using the differential lines of the VME backplane for linking CAN bus lines crate-wise together. Also special crates with monitor backplane, taking the monitor signals from the backplane side (J2) are in discussion.

VII CONCLUSION

This paper describes all necessary types of power supplies which are needed for powering LHC front-end electronics. Further improvements were successfully tested to fulfill all requests at least up to B-fields of 1280 Gauss.

PL 500 /PL 6 systems are suitable for installation in counting rooms with distances to FEE of 120m and more, MARATON for HE installation.

VIII ACKNOWLEDGMENTS

We would like to express our very special thanks to Bruno Allongue for his help, assistance and execution of many radiation and B-field tests at CERN and abroad. Also we are indebted to Ivan Hruska who helped us with the first radiation tests as well as Urs Vogt from Elcotron for all his efforts to arrange first TCC2 tests.

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