BIPOLAR 10 A AND 50 A MAGNET POWER SUPPLIES FOR SWISSFEL

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Abstract

15 years ago the Power Electronics Group at PSI, Switzerland developed power supplies (PS) for the magnets of the Swiss Light Source (SLS). These PS are based on switched mode converters with fully digital control. During the 12 years of operation of the SLS they have shown a very good reliability but also revealed some potential for improvement: After several years of operation the many fans installed started to fail more frequently and the same was observed for "off-the-shelf" AC/DC converters for the DC link. For the new SwissFEL, which shall be in service by 2016, approx. 670 PS rated at 10 A and 20 PS rated at 50 A will be necessary. As for any accelerator application high stability and reliability of the magnet PS are essential for high beam quality and availability. The development of the SwissFEL PS aims to raise the already good reliability by omitting as many fans as possible and adding redundancy for the AC/DC converters. Presently, a prototype rack with 21 10 A PS is available and the mass production has started. The presented paper describes the PS concept and test results of the prototype regarding stability and efficiency are given.

HISTORY AND OBJECTIVES

Generally, accelerator applications require magnet PS with very high stability and reliability at reasonable costs. During the 12 years of operation the PS for the SLS [1] [2] have shown a very good stability and availability [3]. However, three major potentials for improvement have been identified:

- Especially for low power PS the costs for the control boards are too high.
- After approx. 5 years the failure rate of the many fans installed started to increase. This lead to an increased number of beam losses and more maintenance work. Fans shall be omitted wherever possible.
- AC/DC converters: These "Off the shelf" components provide the auxiliary power and – for the low power PS – also the DC-link power. After approx. 8 years we observed increased failure rates also on these components. These converters shall be common for several PS and shall be failure tolerant.

COMPONENTS

10 A DC/DC Converter

Figure 1 shows the 10 A / 24 V DC/DC converter for SwissFEL. It contains a PWM controlled MOSFET H-bridge with input- and output filters and is operated at a switching frequency of 200 kHz. The design is optimized for low losses and low manufacturing costs. The converter has an efficiency of 93% at rated output power. It is installed on a board 100 x 160 mm and can be operated without forced cooling.

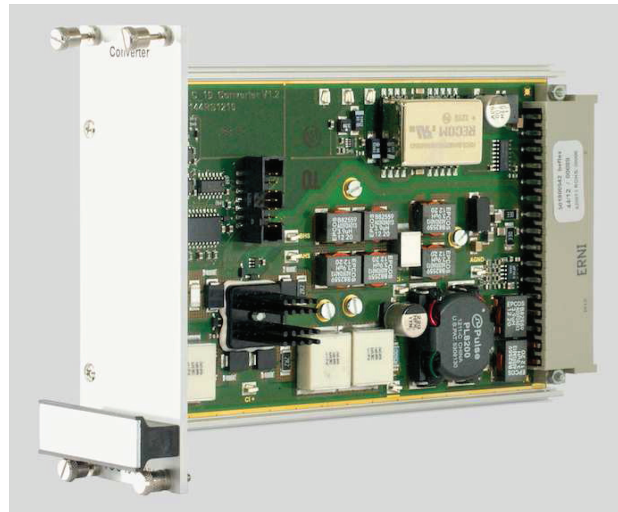

Figure 1: 10 A DC/DC converter.

50 A DC/DC Converter

The 50 A DC/DC converter for SwissFEL is still under development. It consists of a PWM controlled MOSFET H-bridge with input- and output filters, mounted on a printed circuit board. The switching frequency is 100 kHz. The converter will have an efficiency of approx. 85% at rated output power (tentative data) and is installed in a 19" module. It needs forced cooling, which is realized by two fans, whereas one of them is sufficient even at full power. The 50 A zero flux current transducer is installed separately in the cubicle.

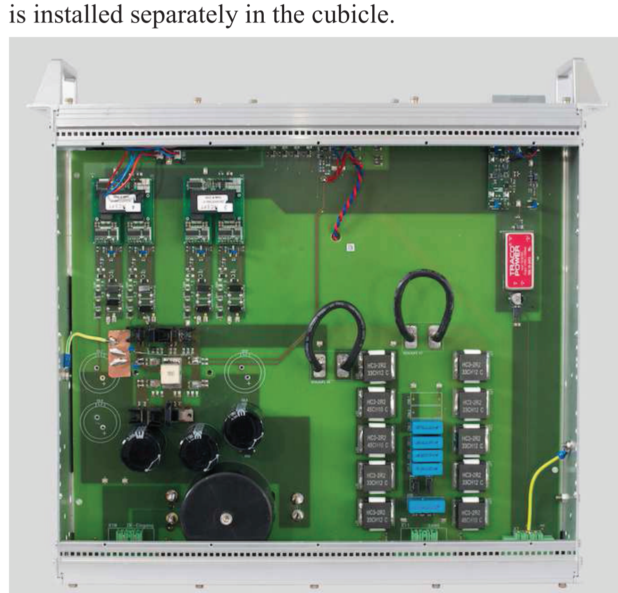

Figure 2: Prototype of the 50 A DC/DC converter.

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Digital Power Electronics Controller

The first generation of this control system used technologies available in the end nineties of the last century. More and more components became obsolete; therefore a major redesign was necessary. The second generation of the Digital Power Electronics Controller (DPC) [4] was developed and a first series of approx. 80 controllers as shown in Fig. 3 is in operation at the SwissFEL test facility since 2 years without problems. The DPC system offers features, which reduce the controller costs significantly:

- The increased computing power of the state-of-the-art components allows for faster control cycles and/or more complex control tasks. For the SwissFEL 3 independent PS are controlled with only one controller board DPC_CC.
- 12 ADC channels have been included on the new controller board DPC_CC. If the stability requirements are relaxed, the separate expensive high-stability ADC board DPC_AD can be omitted. However, the SwissFEL design allows adding that board optionally, if the stability has to be enhanced.

For the majority of PS, we need only ⅓ expensive boards per PS, compared to 2 boards with the 1st generation (SLS). Furthermore the low loss design and the moderate ambient temperatures in the SwissFEL allow the controllers to be operated without forced cooling.

Figure 3: Controller board and high-stability ADC.

10 A POWER SUPPLY CONCEPT

A block diagram of the 3 x 10 A PS design for SwissFEL is given in Fig. 4. Three DC/DC converters, consisting of MOSFET H-bridges with pulse width modulation (PWM), are controlled from one controller board DPC_CC. All the boards are installed in a 19” module (dashed line) together with three zero flux current transducers. Optionally, one output current can be measured with a separate high-stability ADC board DPC_AD, if the stability requirements are enhanced.

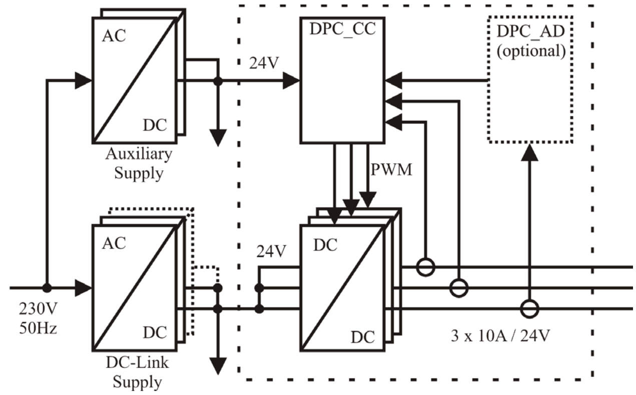

Figure 4: Block diagram of a 3 x 10A PS.

Figure 5 shows a picture of a 3 x 10A PS built into a 19” module. In the front the module contains the controller board DPC_CC, optionally the high-stability ADC board DPC_AD and the three DC/DC converters. In the back three zero flux current transducers plus associated signal amplifiers are installed. All components are interconnected by 2 printed circuit boards, no wiring is required. This eliminates error sources at production and leads to a reproducible EMC behavior. The entire module can be operated without forced cooling.

The modular design allows for rapid replacement of components in case of a failure.

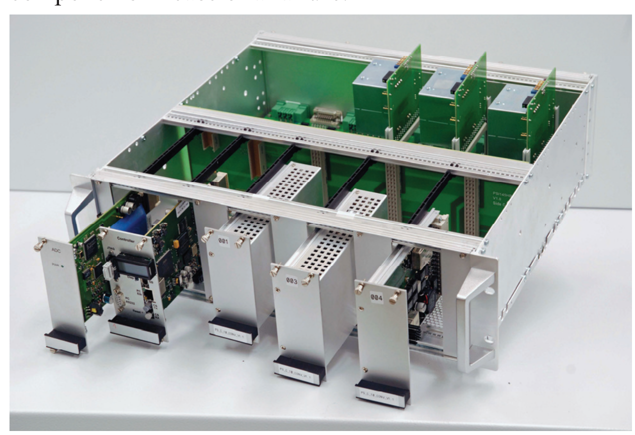

Figure 5: 19” module for a 3 x 10 A / 24 V PS.

Up to 7 such 19” modules with totally 21 PS are installed in a cubicle of 600 mm width, 900 mm depth and 2’300 mm height. The DC link and the auxiliary supply are common for all PS installed in the cubicle. They consist of industrial AC/DC converters available “off-the-shelf” and are paralleled via decoupling devices. In case of a fault, i.e. a short circuit in the output, the decoupling devices prevent the remaining converters from being overloaded. This concept allows n-1 redundancy at reasonable costs.

The cooling concept of the cubicle is based on convection only, even if it is fully equipped and operated at full power.

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50 A POWER SUPPLY CONCEPT

For the 50 A PS the same concept and the same 19” module are used. Instead of one 10 A DC/DC converter and current transducer, one 50 A converter and one 50 A current transducer are installed in a separate 19” module and connected to the controller, as shown in Fig. 6. Up to 4 such 50 A + 2 x 10 A systems are installed in a cubicle as described above.

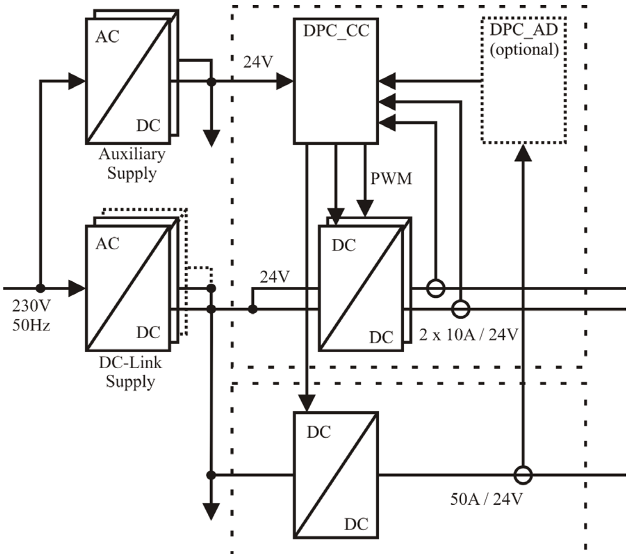

Figure 6: Block diagram of a 50 A +3 x 10 A PS.

RESULTS

Costs and Availability

Compared to the SLS solution, the manufacturing costs per 10 A channel were reduced by approx. 45%. In addition the low losses will lower the operating costs for electrical power and cooling of the SwissFEL buildings.

For the 10 A PS no fans are needed and the unavoidable fans for the 50 A PS are redundant. Also the auxiliary power supply and the DC-link supply are redundant. This will reduce the maintenance effort and the failure rate significantly.

The effort in designing low loss components leads also to a significant increase of the overall efficiency (auxiliary power, DC-link losses, DC/DC converter losses) compared to the SLS solution, refer to Fig. 7.

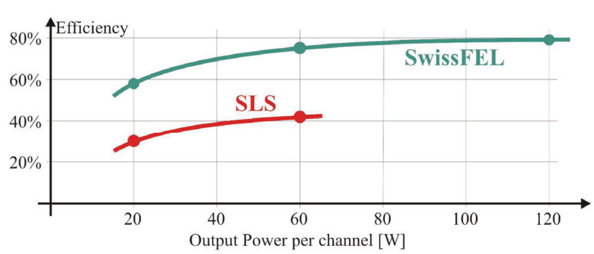

Figure 7: Efficiency Comparison.

Current Stability

For the SwissFEL a high stability of the magnets is essential. Especially the frequency range from 3 Hz ….. 30 kHz is of interest. Drifts below 3 Hz can be compensated by a beam position monitoring system. Current ripple above 30 kHz is damped by the high inductance of the magnets and their low-pass characteristic in the transfer function current-to-field. Therefore the current stability was measured in the frequency range 3 Hz ….. 30 kHz with SwissFEL prototype PS and magnets.

The measurements were taken on SwissFEL prototype magnets and power supplies including 50 m cable between them. The result is not dependant on the load, as long as there is a significant inductance in the circuit. However, if the DPC_AD option is used, the ripple currents are below 10 ppm_{rms}, refer to Table 1 for details.

For the beam quality only the field ripple is relevant. For the current ripple measurements the digitalized data in the controller were analyzed. Besides the real current ripple also measuring noise from the zero flux current transducer and the ADC contribute to the result. Therefore the given results can be seen as worst case figures for the field ripple.

Table 1: Results of Ripple Current Measurements

Magnet Type	**Load**	**Option DPC_AD**	**Current ripple 3 Hz …. 30 kHz**
QFD_C	1.0 Ω / 10 mH	no	<35 ppm_{rms}
QFD_Q	1.3 Ω / 100 mH	no	<35 ppm_{rms}
QFD_Q	1.3 Ω / 100 mH	yes	<10 ppm_{rms}
QFF_C	0.9 Ω / 3.3 mH	no	<35 ppm_{rms}
QFF_Q	1.0 Ω / 33 mH	no	<35 ppm_{rms}
QFF_Q	1.0 Ω / 33 mH	yes	<10 ppm_{rms}

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