11 Power supplies

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11.1 Requirements of the power supplies

The requirements and specifications of the different power supplies for the magnets described in chapter 5 are given in Table 11.1. For the magnets it is proposed to use, as a first step, the same specifications as for the ESRF-EBS upgrade; accordingly this is also proposed for the power supplies [11.1].

In order to power all magnets in a cell individually, 27 power supplies are needed for one cell; with 16 cells this makes a total of 432 current-regulated channels. Adding some spares and the supplies needed for hot-swapping, the number of channels per cell is 36, bringing the total to 576 channels overall. The maximum current for all power supplies is 110 A; the nominal values are 10–20% lower. The accuracy requested varies from 10 to 50 ppm peak to peak, according to beam-dynamic group calculations.

The total quantity of different currents, including correctors to control, is of the order of 800, which is 7 to 8 times greater than for the present machine.

To keep the mean time between failures (MTBF) the same as for the ESRF storage ring, this translates to a requirement of 1500 h of MTBF for the power supply group equipment. Transferred to single power converter, this represents more than 2 million hours of MTBF on average!

Table 11.1: Specifications of the power supplies for the magnets in one cell

me	No. per cell	Coil temp. elevation	Electrical design		**Power supply design**						
			Ohmic coils	Voltage	Current	Over-voltage factor	Cycling current	Cycling voltage	No. power cables included	Cycling power	No. power cables per cell
			[mΩ]	[V]	[A]		[A]	[V]		[W]	
1	2	19.3	145	13.0	86.2	1.28	110.0	16.9	1145	1864	2289
2	2	16	117	11.1	92.3	1.19	110.0	13.6	1057	1501	2114
3	2	10	100	8.4	82.0	1.34	110.0	11.6	710	1278	1420
4	4	12.7	117	9.8	82.0	1.34	110.0	13.6	829	1493	3318
5	2	17.1	117	11.5	95.3	1.15	110.0	13.6	1127	1501	2253
6	2	12.1	188	18.4	95.4	1.15	110.0	21.5	1776	2362	3553
8	2	14.7	224	21.2	91.8	1.20	110.0	25.6	1963	2819	3926
	16										18873
1	2	15	200	17.6	85.5	1.29	110.0	23.0	1523	2531	3046
2	1	9.1	140	12.8	90.0	1.22	110.0	16.0	1174	1757	1174
	3										4220
	4	7.22	125	7.9	62.0	1.77	110.0	14.5	501	1599	2004
	2	8.55	135	8.5	62.0	1.77	110.0	15.6	541	1719	1081
	6										3086
1-2	2	827.0	7.6	3.4	107.3	1.03	110.0	3.7	398	407	796
	2										796
	27			Total power supply power for one cell for main electromagnets							27.0 kW

11.2 Power distribution

For the power architecture it has been decided to use DC/DC converters, fed by an AC/DC rectifier (see Fig. 11.1). In general, up to four cells will be powered by one AC/DC rectifier. For the cells 1 and 16, smaller AC/DC rectifiers will be reused. All the DC/DC converters for one cell will be housed in one cubicle, as shown in Fig. 11.2. The power distribution between the AC/DC rectifier and the DC/DC

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converters for each cell is presented in Fig. 11.3. The power connections between the DC/DC converters and the magnets are given in Fig. 11.4.

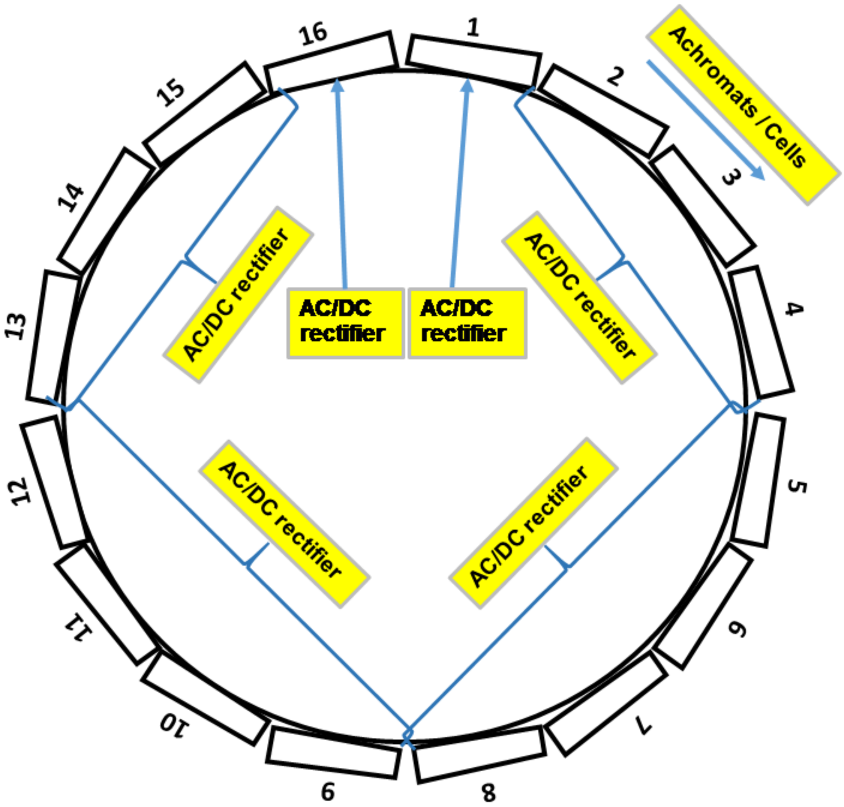

Fig. 11.1: The AC/DC power distribution for the SEE-LS

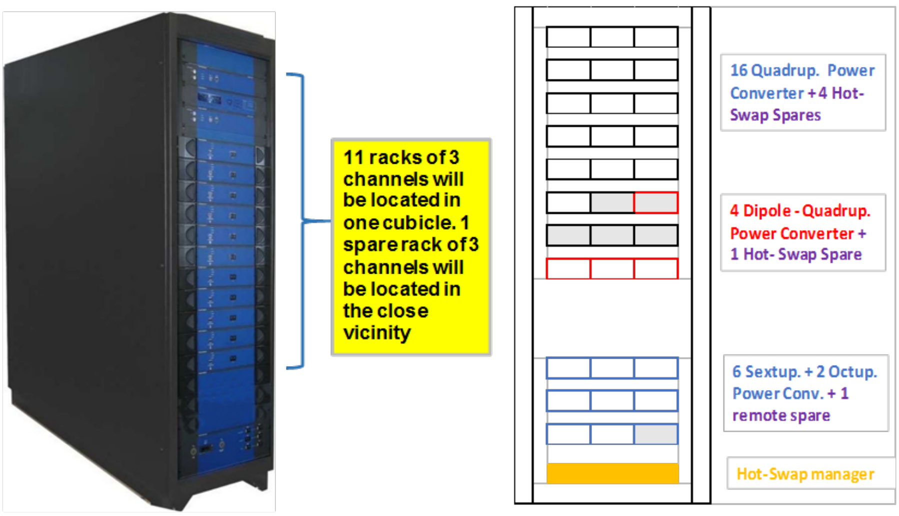

Fig. 11.2: The layout of one cubicle with 11 DC/DC power supplies

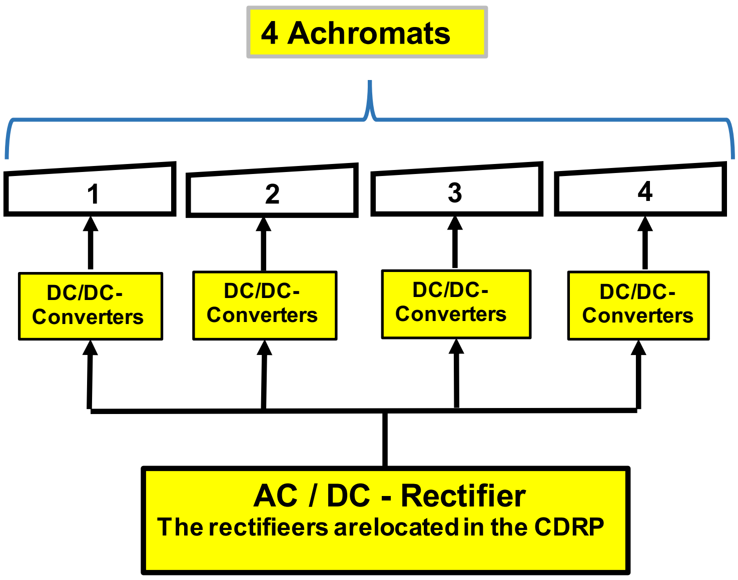

Fig. 11.3: The power distribution between the AC/DC rectifier and the 27 DC/DC converters for each cell/achromat.

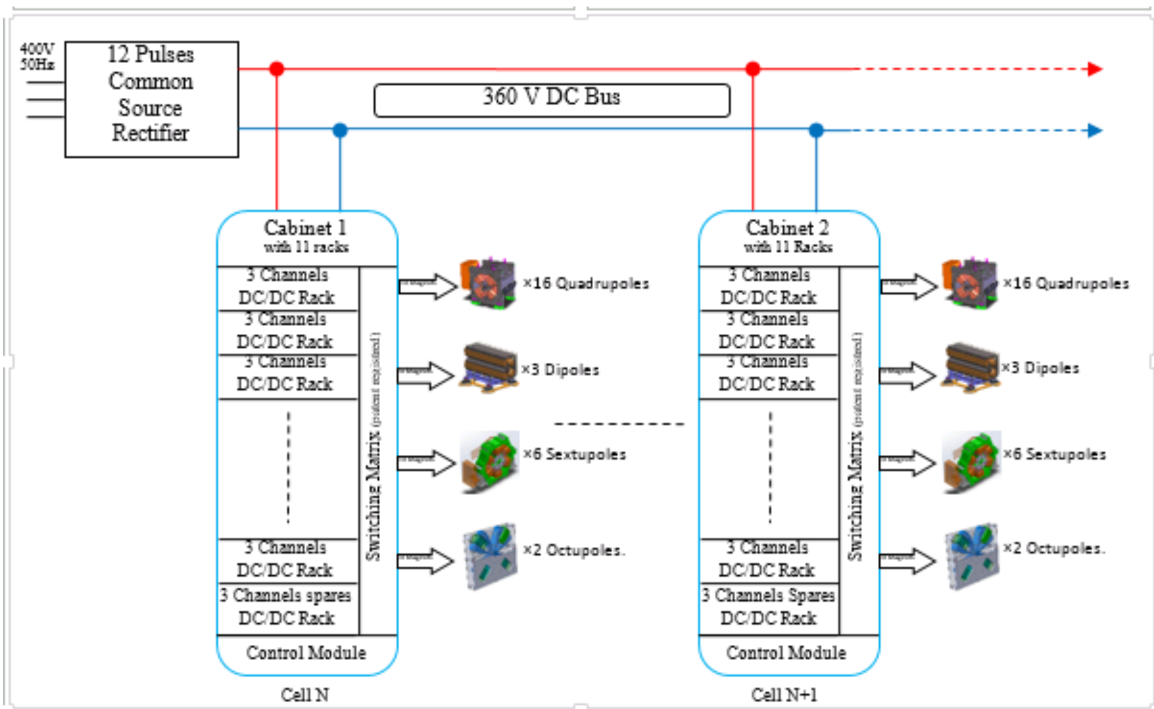

Fig. 11.4: The connections of the DC/DC converters to the different magnets in two cells

11.3 AC/DC rectifier

The purpose of these rectifiers is to ensure a stable voltage at the input of the DC/DC converters. The output DC voltage level is the result of a multi-criteria analysis, which includes evaluation of the prototypes, assessment of availability of the common source park, and optimization of the losses of the DC bus transport infrastructure, among other important tasks. The first analysis proposed in the prototype DC/DC inquiry was from 50 V to 200 V and was based on the APS design. The second analysis indicates that, in order to better reuse the present park of power converters, the voltage 360 VDC optimizes reuse of the family power converter in operation for the present machine and the reuse of the matrix connection board, which lowers the memory type range register (MTRR) in case of a fault in one common source.

The number of these common sources will be 8 (6 large, 2 smaller, and 1 spare), from most of the six family quadrupole power supplies and the three large sextupole family power supplies. This includes the matrix connection, which will be refurbished with the interface renewed and with possible reuse of dipole and superspare units.

11.4 DC/DC converter

The purpose of these power converters is to regulate the output current from a DC voltage bus delivered from the set of centralized AC/DC rectifiers. The minimum number of DC/DC power converters is 27 per cell, and these will be fitted in a standard cubicle of 42 U hosting all electrical input and output links together with the control network, magnet interlock, and cooling water hoses.

To attain an affordable mean time before failure of 3000 h for the complete power supply equipment, study of similar large instruments such as APS and the result of the WP12 validate the idea of procuring a system in which a faulty converter can be replaced while keeping the beam within the vacuum chamber.

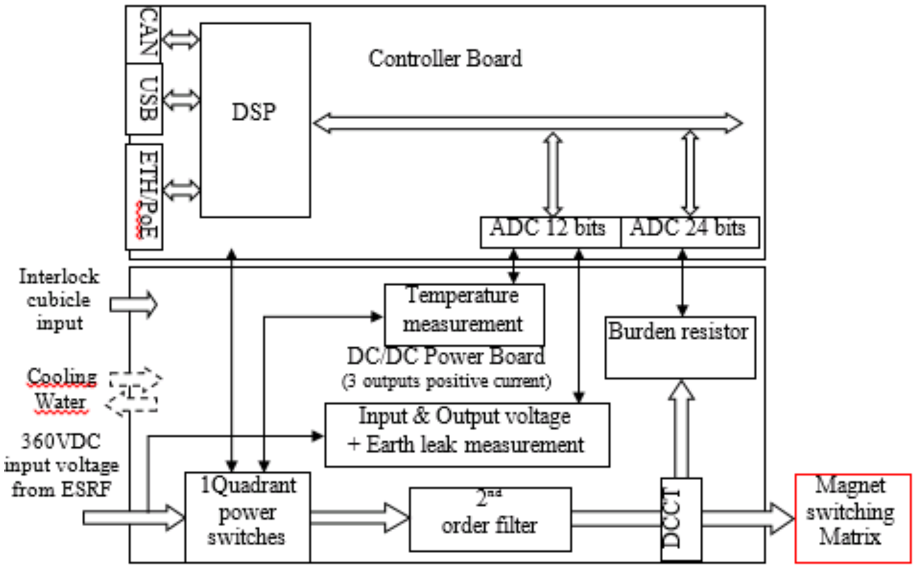

Fig. 11.5: Block diagram of the digital control of the power converter

The 33 DC/DC converters are grouped per cell and located in a single cubicle. A hot-swap matrix will connect 27 outputs from the 33 converters, and the hot-swap manager will survey the output current of the quadrupole and dipole quads; this will enable a fast swap-out of the current source before the beam is lost. This design has been patented by the ESRF under the name ‘hot-swap system’. The sextupole and octupole will be remotely swappable by operator decision to restore one failing channel which is not critical.

The technology chosen is full digital control of each channel adapted to the hot-swap capacity. The use of a standard DC current monitor (DCCT) will be controlled externally by another current sensor to trigger the time to exchange the faulty channel.

For the injection cell equipped with two recovered QD6HGs from cell 16, they will come with their existing power supplies. In order to take advantage of the present architecture, we will refurbish and adapt the switching matrix serving the family power supplies. This will enable main DC distribution (360 V) to be ready in less than half an hour in case of breakdown of one of the eight AC/DC rectifiers.

11.5 Spare power supplies

The goal here is to optimize the number of redundant spares and how they are connected in order to operate with the highest global expected MTBF. The initial approach is to verify how many of the 14 channels need a spare channel. The sextupole and octupole magnets are not necessarily involved with the computer-assisted hot-swapping solution. This is of major importance for the six sextupole main coils because of the coupling factor that exists with the corrector channels attached on the iron poles of the magnets. The theory indicates, as a first estimation to be confirmed, that a loss of one sextupole magnet does not kill the beam; only the chromaticity is changed and could be partially compensated for. As a consequence, a solution with a maximum of nine channels per cell equipped with the hot-swapping solution is the first case under evaluation.

The second issue is the number of spare channels to implement, which is governed by the reliability study and also by the minimum availability of standalone channels. This depends on the final electrical, mechanical, and connectivity implementation. The target is to have an independent Ethernet rack driving the redundant channels; the mechanical connectivity has to be identical to that for the 'normal channel'—two, three, or four channels per rack on the same external DC bus. For example, if the power converter rack has four channels built in, we would need four racks to power 13 channels, and one four-channel rack could serve as a set of redundant units for the nine critical ones. If a rack has three channels built in, we would need four racks to power 13 channels per cell, plus one or two additional racks housing two or three channels that could serve as redundant channels for the nine critical ones.

11.5.1 Minimum implementation

The solution having eight quadrupole magnet power converters backed up by four spares produces a very high MTBF and allows the standby team to exchange the first faulty channel the next morning, rather than waiting for the next mean down time (MDT) maintenance period one week later. This is true only if the channels are grouped by twos at most in one enclosure. The case with three channels per enclosure pushes us to have two racks as spares in order to be able to wait until the next MDT to exchange the faulty channel.

The non-computer-assisted faulty channel replacement will be implemented in the form of one spare for the three DQs and one spare for the six sextupole and two octupole DC/DC converters. Remote exchange of one channel could possibly be launched from the control room with a procedure yet to be worked out. With this minimum implementation, the number of channels to order per cell will be 33 (16 + 4, 3 + 1, and 8 + 1), for a total of 1056 converters in operation; the spare units will be added to this number according to the philosophy adopted at the contract placement.

11.6 The AC and DC corrector power supplies driven by the fast-orbit feedback

For the AC steerers, the plan is to fully reuse the Bilt power supplies connected to the fast-orbit feedback and the Libera units in operation (see Fig. 11.5) below the running power supplies. Only the location of the cubicles will be subject to discussion with the aim of optimizing the technical gallery space and the control cabling.

These power supplies are currently the ones in operation linked with the Libera units and the computer preparing the set points at 10 kHz for the 288 channels. We foresee no changes to this system, and the latest (Bilt) power supplies will be connected to the special steerers designed for this purpose.

The electrical compatibility in terms of AC coupling and bandwidth is yet to be verified, but this cannot be performed before the first magnet prototype has been delivered.

11.7 The DC corrector power supplies feeding the sextupole auxiliary coils

Some magnets are equipped with auxiliary coils, such as the sextupole magnets and the dipole–quadrupole magnets, and will be powered separately.

The six coils wound around the six sextupole magnet poles per cell will perform vertical, horizontal, and skew adjustments and will therefore need a total of 768 channels (4 circuits per sextupole × 6 sextupoles per cell × 32 cells). The present electrical ratings are 2 A and 11 V per channel, leading to 22 W, and we have chosen not to reuse the actual 250 W corrector power supplies (180 units) because of poor reliability, the interface not being supported any more at the control room, and an insufficient number for the new lattice. A survey is needed to evaluate whether an industry-standard commercial product is affordable or if some neighbouring institute would be willing to sell an appropriate design and realization.

This same DC distribution scheme will also be used for the corrector DC distribution (45 V). The switching matrix will be split with more buses to accommodate such a strategy

A DC bus distribution at 45 V will be refurbished from three of the five flexibility power supplies used for high-focusing optic configurations. This will be the input power for 24 channels (4 × 6 sextupoles per cell) times 32 cells, i.e. 768 DC/DC corrector channels.

11.8 Earth magnetic field compensation power supplies

The present lattice is equipped with two types of field compensation. The first type compensates for the algebraic sum of the family current passing through the straight section. One big loop is fed by the Flex 1 on request during all runs except for the 16-bunch mode. The second type of compensation is performed under a chosen set of straight sections at the request of the WP8 and is fed by individual power supplies connected to a four-wire cable laid just under the insertion devices, with return outside the tunnel. According to the WP8, the new lattice requires that all straight sections be equipped with compensating loops, and furthermore the two planes need to be adjusted for earth field. The maximum total quantity is therefore 54 (2 × (32 − 5)) in operation, with some spares in case of failure.

The present solution using low-grade power supplies could be extended by reusing the 12 units in operation today. A request for quotation (RFQ) will therefore be necessary when the power size is known. We are also looking to power the units with the DC corrector (2 A 26 W) solutions, adding the 54 requested to the 768 described in section 11.7.

We will soon obtain the magnetic earth field correction current request. This should complete the array of power supplies to procure.

The general layout of power converters for accelerators is presented in Ref. [11.2].

References

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