CHAPTER 4

UPGRADING THE PSB TO 1.4 GeV – POWER SUPPLIES

4.1 MAIN MAGNET POWER SUPPLY AND REACTIVE POWER COMPENSATOR

The output energy of the PSB has been increased from 1 to 1.4 GeV. This required an increase of the magnetic field by about 26% to 0.87 T, which was obtained by raising the coil current of the main magnets. The rms current was raised from 2000 A to 2300 A and the peak current from 3300 A to 4050 A at a maximum magnet voltage of nearly 3800 V (the magnet circuits are tested up to 10 kV).

The main magnet power supply has to cope with a significant increase of the peak power (from 8 to 14 MVA for the LHC cycle) which made the redesign of the rectifier transformers and the reactive power compensation system necessary in order to keep the line voltage variations to a minimum.

The upgrade [1] allowed the phasing out of the old polychlorinated biphenyl filled transformers and reactors.

4.1.1 Topology of the Upgraded Main Magnet Supply

The PSB main magnets are powered from the 18 kV line directly without energy storage. A high power fast-pulsed power supply (14 MVA peak power, 1.2 s repetition rate) feeding an inductive load and operated directly from the utility power lines presents a dynamic load that causes voltage and phase variations in the transmission system. The amount of disturbance is directly proportional to the dynamic load and inversely proportional to the short circuit capacity of the power system.

To minimise these effects on the AC lines and to increase the DC performance of the load, the PSB power supply is built as a series connected group of four 12-phase rectifier modules with freewheeling thyristors connected to the star point of the transformers. This circuit arrangement has the advantage of requiring less reactive power on the AC side. With respect to a normal 12-phase-bridge, it significantly reduces the output ripple on the DC load. Therefore, a smaller passive ripple filter can be used. The power system scheme is shown in Fig. 4.1 and the 1.4 GeV magnet cycle in Fig. 4.2.

4.1.2 The Reactive Power Compensation

The scheme described above reduces the line harmonics on the 18 kV side and minimises the reactive power variations, but not sufficiently.

To obtain satisfactory reactive power compensation and sufficiently low total harmonic distortion, an existing 18 MVAR capacitor bank and harmonics filter on the 18 kV level near the Jura substation at the Meyrin site is used [2]. The dynamic compensation is delivered by a set of Thyristor Controlled Reactors (TCR) installed next to the filter. All the filtering and compensating equipment is connected to the power distribution system at the 18 kV level.

Particular care has been taken of the TCR control circuitry to ensure that variations of the network voltage are kept to a minimum. The TCR was specified [3] and installed by the CERN power distribution group and ordered within the Canadian collaboration with TRIUMF.

During the 1.4 GeV cycle the variation of the line voltage on the 18 kV network is of the order of 2.3% without and 0.5% with compensation. The latter figure contains other variations in the network, as it is impossible to do measurements with an ideally stable network (see Fig. 4.2).

4.1.3 The Power Converter Groups

The original rectifier groups (four plus one spare) have been refurbished to deal with the increased rms and peak power for the LHC cycle. However, the water cooling of the freewheeling thyristors had to be upgraded and additional heat sinks for the fuses were installed to decrease their temperature.

The CERN power distribution group installed a complete, new 18 kV switch gear with the connection to the primary of ten new rectifier transformers (two units in one tank, rated 18kV/410V/2x 1.35 MVA). The latter were ordered as part of the Canadian collaboration with TRIUMF. The transformers were specified to be housed in the same position as the former transformers in order to retain the same phase symmetrical connections to the rectifier bridges.

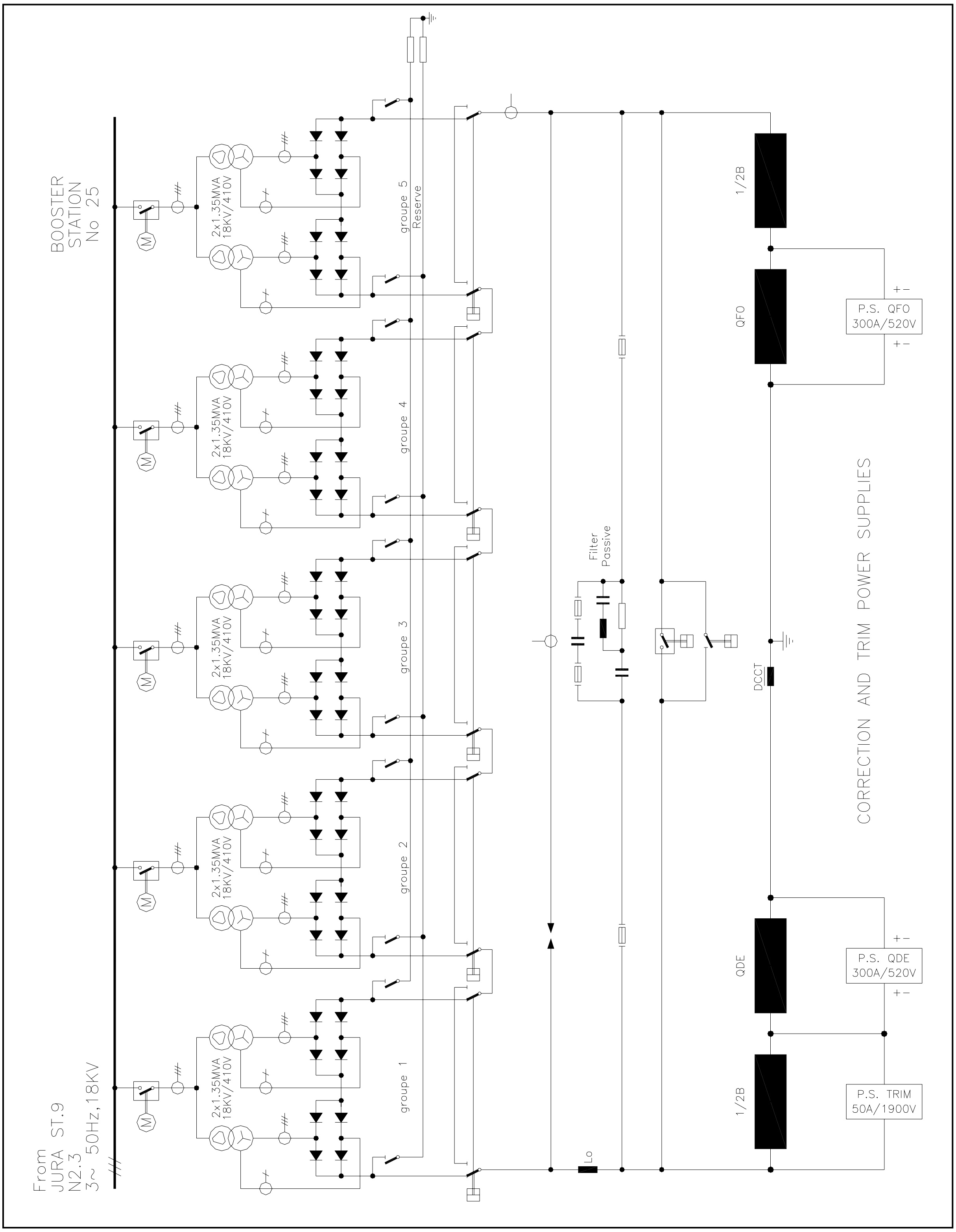

Figure 4.1: PSB main magnets supply electrical diagram.

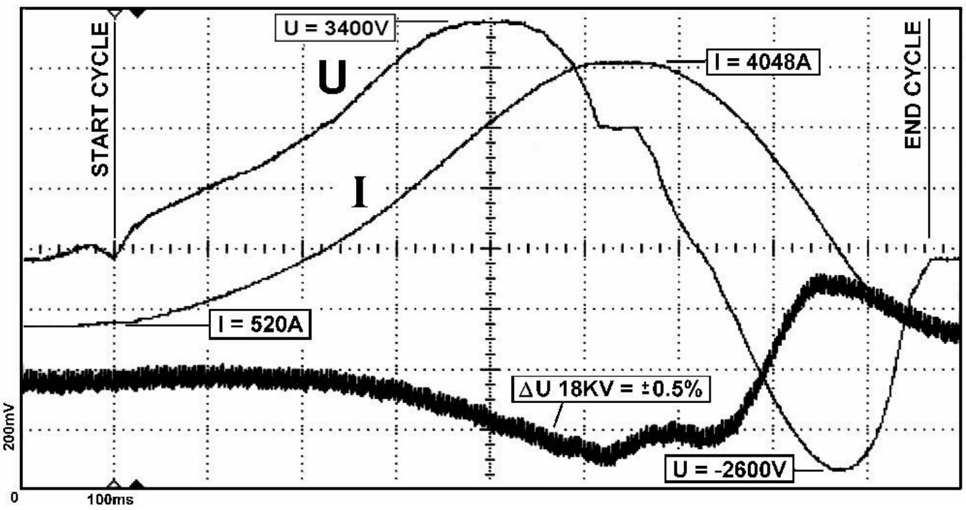

Figure 4.2: Voltage (U) and current (I) of the 1.4 GeV cycle and voltage excursion (ΔU) on the 18 kV network, 100 ms/div.

A polygon-primary to star-secondary coupling was specified for the transformers in order to connect the freewheel thyristors to the neutral point and to have a higher turns ratio for the accuracy of the phase angle (±15° el. with a tolerance of 0.03°). Also much care was taken to ensure that the absolute impedance (4%) of all ten transformers had limited spread within phases and units (± 5%). Both efforts were necessary to keep sub-harmonics (50, 100 Hz) as low as possible [4].

The over-voltage protection circuits on the secondary of the transformers were redesigned and adapted to the new layout.

The DC output connections of the rectifier modules (1000 V / 2300 A rms / 4050 A peak), the DC switching circuitry for the series connection of up to four groups, the passive filter and the connections to the magnets have been taken over from the old system.

4.1.4 Regulation and Control Electronics

A magnet cycle editor in the control system allows the creation and storage of cycles for different beam requirements. These cycles are sent to the main magnet supply via the local Device Stub Controller (DSC).

Input to the current regulation electronics is the base current from the PS control interface MIL1553 bus and, via a serial digital function generator, the LdI/dt function. By measuring the magnet current with a DC Current Transformer (DCCT) and using a Digital Signal Processor (DSP) the IR component is added to the LdI/dt component to calculate the reference voltage for the magnet. By integration of the LdI/dt function a current reference is created and compared to the actual current. The difference corrects the reference voltage signal and eliminates the influence from the resistive (thermal) variations of the magnet [5]. A block diagram of the regulation is shown in Fig. 4.3.

The magnet voltage reference signal is distributed to the four rectifier groups and successively controls the groups from zero to full voltage. Each rectifier group has its dedicated voltage feedback loop. This enables the variation of the reactive power consumption to be reduced and to keep the ripple of the voltage of the modules in series as low as possible.

The control of the 12 pulse rectifier-inverter bridges is done by high precision linearised gate control sets with a resolution of 0.1° el.. There are two separate functions for each group: bridge mode and freewheel mode. During start up the firing pulses of the selected groups have to be synchronised and switched from freewheel to bridge mode. In case of a major fault the freewheel thyristors act as a crowbar and thus protect the main magnets.

Disturbances with harmonics of the supply's commutation frequency have been observed on the current and field measurements. The modification of the grounding of the magnet circuit and the installation of a common mode filter at the output of the power supply improved the situation [6].

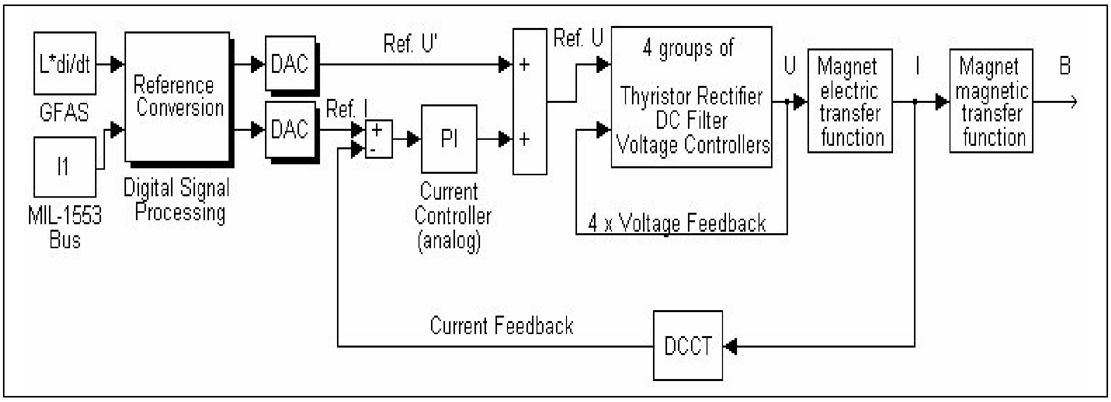

Figure 4.3: Block diagram of voltage and current regulation using digital reference processing.

Most of the control and interlock functions as well as the digital part of the power supply interface to the control system are performed by decentralised Programmable Logic Controllers (PLCs) interconnected by a serial fieldbus. Some vital functions (e.g. overcurrent) are hard wired in parallel to the PLC. The Mimic diagram and local and remote control are also integrated in the PLC system.

4.1.5 Quadrupole Correction Power Supplies, QFO and QDE

All bending and quadrupole magnets of the PSB machine are connected in series. To control the quadrupole magnets separately within a span of 8% of the main current, two correction power supplies are connected in parallel to the quadrupoles (see Fig. 4.1). These power converters are 12-phase thyristor-controlled rectifiers with passive and active fast filters in series with a current precision and tracking error better than 10^{-3} of nominal current and high dynamic capability (4 kA/s). Nominal ratings are 300 A / 520 V / 150 kW. The insulation to ground withstands 10 kV, the same as the entire main magnet circuit [7].

4.2 MAIN BENDING MAGNETS "TRIM" POWER SUPPLY

During the running-in period (in 1998) after the upgrade of the PSB to 1.4 GeV it became clear that the main bending magnets showed more effects of saturation than had been anticipated. The field values for the outer rings (rings 1 and 4) were slightly smaller as the magnet had been shimmed [8] to equalise field values at the former ejection energy of 800 MeV.

To equalise the bending fields the idea of the installation of a trim power supply was developed. Investigations of the cabling of the coils of the bending magnet string showed that the coils for rings 1 and 4 as well for rings 2 and 3 are in series with connection points accessible from the power supply equipment room.

A switch-mode power supply was specified, ordered, constructed, installed and commissioned in a record time of 4 months [9, 10]. The main characteristics are:

- bipolar 1900 V
- current 0 – 50 A with 10 A_{rms}
- total precision ±0.2% (ripple, tracking error, disturbance) relative to the maximum current of the main supply;
- stable operation at zero current;
- radiated and conducted switch noise below 50 mA_{pp}
- insulation to ground 10 kV, as the whole main magnet circuit.

To anticipate a step increase of the main current, the bending magnets voltage signal is used as a feed-forward voltage reference for the trim supply. This allows the tracking error of the trim supply to be reduced to nearly zero.

Control and interlocks of the trim supply are integrated into the PLC system of the main power supply like the QFO- and QDE- supplies (focusing and defocusing quadrupole magnet trim supplies)and they are controlled by the same knobs as the main supply.

4.3 PSB–PS/ISOLDE BEAM-LINE POWER SUPPLIES

The PSB-PS beam transfer line was designed in the late sixties for 800 MeV protons. In mid 1980 the PSB was upgraded to 1 GeV without modifying the transfer line equipment. More recently it was decided to upgrade further to 1.4 GeV for future LHC operation while also making available 1 or 1.4 GeV beams to the ISOLDE facility. Consequently, a number of magnets and power converters of the PSB transfer lines had to be replaced and this work was carried out in co-operation with TRIUMF, taking advantage of the Canadian in-kind contribution to the LHC project.

4.3.1 Requirements

The characteristics of the transfer line magnets and the related power supplies, as well as the operational requirements at 1.4 GeV, are shown in Tab. 4.1 and Tab. 4.2. Some of the magnets are DC while others require modulation during the 600 ms between field values corresponding to 1 and 1.4 GeV or even zero. One magnet (BT.BHZ10), which directs the particles almost symmetrically either to the PS or to the ISOLDE / PSB measurement-line, has to perform a full current reversal at 1 or 1.4 GeV within less than 750 ms. To allow a certain flexibility during operation in the years to come, a suitable margin in voltage and current was provided when specifying the new power supplies.

Table 4.1: Main operational parameters of power converters up to 35 kW and of related magnets (“B” means bending magnet, “D” correction dipole, “Q” quadrupole. “PPM” stands for “Pulse to Pulse current Modulation” every 1.2 s).

Function	Item	Identification	Magnet	DC Resistance	Operation at Imax (1.4GeV)		Power Supply	Remarks	Notes
			Type	(w. cables) (Ω)	Current (A)	Voltage (V)	Type		**Magnets:** mH / mΩ / ms
PSB Injection Line	1	BI-BVT	B5 (°)	0.175	250 (*)	44	a2	ppm1	**B** : 43 / 221 / 194
	2	BT1-BVT10	**B**	0.246	281	70	a2	ppm	**B1**: 92 / 422 / 218
	3	BT4-BVT10	**B**	0.246	281	70	a2	ppm	B4: 205 / 94 / 2180
	4	BT-BVT20	**B1**	0.442	244	109.5	268 A -118 V	ppm	B5: 31 / 160 / 194
	5	BT2-DVT10	**D**	0.09	147	13.5	a1	ppm (+/-)	B6: 11 / 85 / 130
	6	BT3-DVT10	**D**	0.09	147	13.5	a1	ppm (+/-)	B7: 15 / 110 / 136
	7	BT2-DVT20	**D**	0.09	248	22.5	a1	ppm (+/-)	**D** : 3.2 / 80 / 40
PSB Transfer Line	8	BT3-DVT20	**D**	0.09	248	22.5	a1	ppm (+/-)	**Q** : 48 / 160 / 300
	9	BT3-DVT40	**D**	0.09	124	11.5	a1	ppm (+/-)	Q1: 160 / 260 / 615
	10	BT2,3-QNO10	2 X **Q**	0.35	199	71.5	a2	ppm	Q2: 240 / 200 / 1200
	11	BT2,3-QNO20	2 X **Q**	0.35	189	68	a2	ppm	(**Bold** = new TRIUMF magnet)
	12	BT-QNO30	**Q**	0.18	88	16.5	a1	ppm	**Power Converters:**
	13	BT-QNO40	**Q**	0.18	259	48	a2	ppm	Type a1: 300 A - 50 V (18)
	14	BT-QNO50	Q1	0.27	197	60	a2	ppm	Type a2: 350 A - 90 V (9)
	15	BTP-QNO10	Q (°)	0.185	150	28	a1	dc (**)	Type a3: 500 A - 70 V (2)
	16	BTP-QNO20	Q (°)	0.185	145	27	a1	dc (**)	**Batch1: 21xa1+ 11xa2 + 6xa3**
PS Injection Line	17	BTP-QNO30	Q (°)	0.2	139	28	a1	dc (**)	**Operations:**
	18	BTP-QNO40	Q (°)	0.2	177	35.5	a3	dc (**)	ppm : 1 / 1.4 GeV
	19	BTP-QNO50	Q	0.2	152	30.5	a1	dc (**)	ppm1: protons / ions
	20	BTP-QNO60	Q (°)	0.215	176	38	a1	dc (**)	**I***1* **:** **I***1.4* = 0.79 **:** 1
ISOLDE Line	21	BTY-BVT116	B4	0.11	410	45	a3	dc	**I** (*ions*) = 1.12 x **I** (*protons*)
	22	*BTY-QDE209*	Q2 (°)	0.23	174	40	*a1*	dc	Δt available for ppm: 600 ms
	23	*BTY-QFO210*	Q2 (°)	0.23	221	51	*a2*	dc	
GPS Line	24	*BTY-DHZ212*	**D**	0.1	243	24.5	*a1*	dc (+/-)	(+/-) = mechanical - remote
	25	*BTY-DVT212*	**D**	0.1	243	24.5	*a1*	dc (+/-)	controlled - polarity changer
	26	*BTY-BHZ308*	B4	0.13	410	53.5	*a3*	dc	(*): Ions injection into the PSB
	27	*BTY-QDE321*	Q2 (°)	0.23	174	40	*a1*	dc	(**): ΔI in ppm < 5%
HRS Line	28	*BTY-QFO322*	Q2 (°)	0.23	221	51	*a2*	dc	(°) : Solid yoke
	29	*BTY-DHZ324*	**D**	0.1	243	24.5	*a1*	dc (+/-)	(°°) : Secondary beam
	30	*BTY-DVT324*	**D**	0.1	243	24.5	*a1*	dc (+/-)	Location: BHP - *ISOLDE Hall*

Table 4.2: Main operational parameters of power converters with 100 and 250 kW ratings and of related magnets (“m1-4” means magnet. Other symbols as in Table 4.1).

Function	Item	Identification	Magnet	DC Resistance	Operation at Imax (1.4 GeV)		Power	Remarks	**Magnets:** mH / mW / ms
			Type	(with Cables)	Current	Voltage	Supply		**m1**: 92 / 480 / 192
				(Ω)	(A)	(V)	Type		m2: 470 / 200 / 2350
									m3: 370 / 400 / 925
PSB Transfer Line	1	BT-BVT20	**m1**	0.5	244	123	b1	ppm	m4: 205 / 94 / 2180
									Power Converter types:
	2	BT-BHZ10	m3	0.42	(+/-) 381	488 (398)	b2	ppm	Type b1: 500 A - 200 V (4)
Switchyards	3	BTY-BVT101	m4	0.11	397	158.5	b1	ppm2	Type b2: 450 A - 550 V (1)
	4	*BTY-BHZ301*	*m4*	*0.13*	*397*	*163.5*	*b1*	ppm3	**Batch-2: 6xb1 + 2xb2**
									ppm2: 0 / 1 or 1.4 GeV
Measuring Line	5	BTM-BHZ10	m2	0.22	446	161	b1	ppm	ppm3 = ppm2 for GPS / HRS
									Δt available for ppm: 600 ms
									(0.75 s for BT-BHZ10)
									(+/-): bipolar power supply b2

4.3.2 Performance Specification

The critical specifications for the new power supplies [11, 12] concern:

- the operational DC precision/stability of current referred to nominal set-point, to be better than $1\cdot10^{-4}$ over 8 hours
- the capability of changing the current by ± 25%, or by 100% in some cases, within 600/750 ms – regulation transients included, on subsequent PSB cycles
- the conformity to the PS control interface (MIL-1553) and to the operator interface in use in the PS complex
- the use of state of the art circuit topologies so as not to become obsolete once the LHC starts operation.

With the view of simplifying the design of the power parts, the operational requirements of the transfer line magnets were met by two sets of power supply ratings: a lower range up to 35 kW (Batch-1) and a higher one up to 250 kW (Batch-2). Consequently the following types of power converters have been specified (Tab. 4.1 and 4.2):

- Batch-1 (38 units): type a1=15 kW (300 A, 50 V) with mechanical output current polarity selector; a2=31.5 kW (350 A, 90 V) and a3=35 kW (500 A, 70 V).
- Batch-2 (8 units): type b1=100 kW (500 A, 200 V) and b2=250 kW (450 A, 550 V).

4.3.3 Technical Solution

Using today’s state of the art technology, Switch Mode Power Supplies (SMPS) have been specified, which have excellent precision/stability, low losses and fast regulation response [13].

As an illustration of the design, a block diagram of the power section of the 100 kW converter is shown in Fig. 4.4. Specifically, the power section of the converter consists of an AC series-parallel input filter to reduce current harmonics and raise the power factor; a rectifier and filter forming the DC link; an Insulated Gate Bipolar Transistor (IGBT) full H-bridge operating at a switching frequency of 16-18 kHz and a ferrite HF transformer with centre tap secondary, feeding a high current rectifier followed by two *LC* passive filter stages. To achieve a 600 ms current fall time despite of a load time constant of over 2 s in some cases an optional regeneration thyristor bridge provides the required negative voltage on the magnet and an IGBT switch isolates the converter from the load when the current is requested to decrease to zero.

The 250 kW converter has three IGBT H-bridges working in parallel and feeding the HF transformer which has its secondary connected to a Graetz-bridge rectifier followed by two *LC* filters. In addition to the regeneration section, this converter has a thyristor selector of the DC current polarity which allows an inversion of the field which directs the protons either to the PS or to the ISOLDE/measurement line. The semiconductor switches and some of the magnetic components are water cooled to obtain the compact assembly required by this type of converter for electromagnetic compatibility reasons.

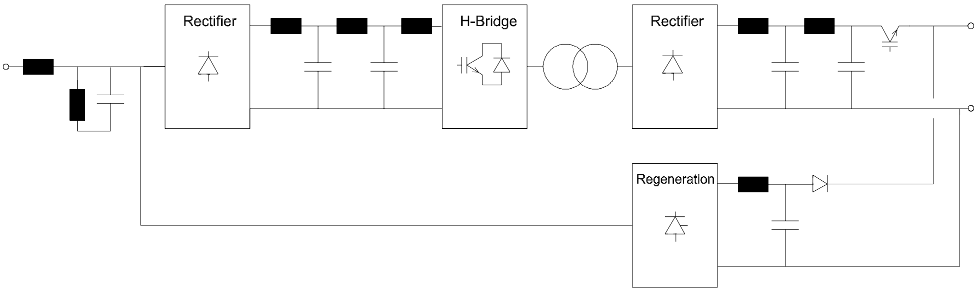

Figure 4.4: Block diagram of a 100 kW switch-mode power converter.

All the voltage and current measurement systems used for monitoring, protection or feedback are insulated. The power supply output current is measured via high precision magnetic sensors (DCCTs).

The regulation of such a SMPS (Fig. 4.5) consists of several cascaded feedback loops:

- A first loop balances the current in the two arms of each IGBT H-bridge to avoid saturation of the HF transformer by any DC component.
- A second loop controls and limits the current I_p on the primary of the HF transformer.
- A third fast loop controls the voltage U_r at the rectifier output.
- Finally the overall feedback loop controls the current and ensures the stability and precision.

The critical components of the current loop are enclosed in a Peltier oven block kept at constant temperature by a separate regulation.

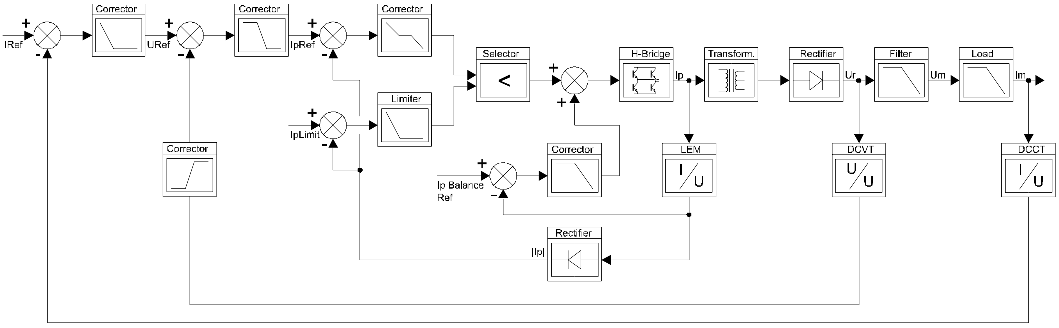

Figure 4.5: Block diagram of final power converter regulation.

As factory tests could not be performed on the actual load, the regulation had to be slightly modified and adjusted during commissioning at CERN. This results in the best possible dynamic and static behaviour over the full current range.

To make the power supply electronics compatible with CERN standard control and operator interfaces, the principle of separating a 6U Euro-crate in two 3U sections was adopted. The upper one was reserved for CERN specific boards and the lower one for the manufacturer's electronic cards. This solution has been shown to work smoothly and to allow a clear definition of responsibilities with a minimum of interfacing conflicts.

4.3.4 Project Wind Up

Having equipment specified at CERN and built in Canada proved difficult. In addition to the distance and time lag, the different workmanship quality standards, work methods and materials in use, as well as the different culture of the North American market, have proved to be quite challenging. From the beginning the arrangement that CERN would prefer to take care of the follow up of technical aspects and of the compliance with the specification and leave TRIUMF the role of managing the contracts and dealing with the suppliers, worked quite well. The power converters were designed, developed and manufactured by firms based in Toronto. Several hundred CERN specific interface boards for all the power supplies were made, stuffed and pre-tested by a specialised firm located in Vancouver.

All supplies have shown excellent performance and availability records. The Batch-1 power supplies have been in operation since March 1998 and the delivery of Batch-2 power supplies was completed in 2001.

4.4 PULSED POWER CONVERTERS FOR SEPTUM MAGNETS IN THE PSB-PS LINE

The upgrading of the PSB-PS recombination and transfer line to 1.4 GeV called for new pulsed septum magnets to replace the unsuitable DC septa (see Chap. 5.1). For the new septa, new pulsed power converters have been designed and installed in the transfer line PSB-PS. To meet the main features such as high current, high precision and duration of the flat-top and to master thermal and magnetic problems owing to the irregular pulses (current and timing modulation), a third harmonic correction of the discharge pulse was added and an active filter inserted [14].

A new electronic crate has been developed at CERN to facilitate the maintenance and to respect different criteria: standardisation, protocol, timing and regulation with active filter. The power parts have been designed at CERN and built in collaboration with industry.

4.4.1 Operational Requirements

In the common part of the transfer line between PSB and PS, the kinetic energy is either 1 GeV (ISOLDE at low energy) or 1.4 GeV (PS and ISOLDE at high energy). The PS supercycle is made of basic cycles (1.2 s length) dependent on the use of different beams. Consequently, pulsed power converters must work with an irregular pulse repetition and with pulse to pulse modulation of their current.

The recombination of the beam in the PSB transfer line uses: four superimposed horizontal septa (BE.SMH with the four magnets in series), three vertical septa (BT1.SMV10, BT4.SMV10, BT.SMV20) and a horizontal septum for the injection in the PS (PI.SMH42).

4.4.2 Pulsed Capacitors Discharge Power Converters

The principle is based on the charge and discharge of capacitors through a resonant circuit between capacitors and load. The charging current of the capacitors is controlled via thyristors on the primary side of a high voltage transformer. The DC voltage and current are measured by voltage dividers and shunt. Once charged, the capacitors are discharged in the magnet via a power thyristor. In order to obtain a better flat top current than the basic sinusoidal discharge current, a third harmonic with parallel *LC* circuit is added. A choke, in series with the discharge circuit, is used for the active filter. The discharge is through a matching transformer whose secondary delivers 4 to 12 times the primary current to the septum magnet.

4.4.3 Matching Transformer and Strip-line

The matching transformer is a specially manufactured device with an air gap and a very low stray inductance. It is installed in the ring and the secondary of the transformer is connected to a magnet vacuum feedthrough via a high current strip-line. This is made of copper plates to minimise the value of inductance and to keep the resistance small relative to the magnet. The current in the septum is monitored by a current transformer between the pulse matching transformer and the high current strip-line.

4.4.4 Regulation and Active Filter

The capacitor voltage is regulated with a charging current internal loop. Temperature variations and magnetic effects caused by irregular repetition rate are regulated by special electronics which slightly increases or decreases the capacitor voltage.

A flat top current stability of 10^{-4} is achieved by an active filter power circuit with a regulation control loop. The principle is to charge the main capacitors slightly more than the value necessary to give the current wanted. The excess current is then pulled through the inductance of the active filter and the system acts in a closed loop through the matching transformer. More details may be found in [14 and 15] and in the specification document [16].

4.4.5 Characteristics of the Power Supplies

The principal characteristics of the power converters are resumed in Tab. 4.3:

Table 4.3: Main parameters of the pulsed septum magnet power supplies.

		BE.SMH	**BT1.SMV10**	**BT4.SMV10**	***BT.SMV20***	***PI.SMH42***
Peak current septum	A	6000	30000	30000	30000	40000
Transformer turn ratio	n1/n2	4	12	12	12	12
Charging voltage	V	1200	2100	2100	2100	2100
Peak current primary	A	1500	2500	2500	2500	3333
Total storage capacitors	µF	2500	2000	2000	2000	3000
Energy storage capacitors	J	1800	4410	4410	4410	6 615
Total inductance secondary	µH	22	3	3	3	2.03
Total resistor secondary	µΩ	4020	660	660	660	620
Current pulse half period	ms	3.6	3.5	3.5	3.5	3.6
Current pulse flat top	µs	500	500	500	500	500
Current flat top precision	ppm	< 100	< 100	< 100	< 100	< 100
Pulse to pulse modulation		yes	yes	yes	yes	yes
Irregular pulse repetition		yes	yes	yes	yes	yes
Max. pulse repetition rate	Hz	1	1	1	1	1
Third harmonic choke	µH	248	370	370	370	280
Active filter choke	µH	50	50	50	50	50
Inductance seen by primary	µH	432	503	503	503	372
Power transformer 3 ph.	kVA	20	63	63	63	63
Prim./second. voltage effective	V	400/1000	400/2000	400/2000	400/2000	400/2000

Typical discharge and filter currents are shown in Figs. 4.6 and 4.7, with a current of 33 kA in the PI.SMH42 septum magnet [15].

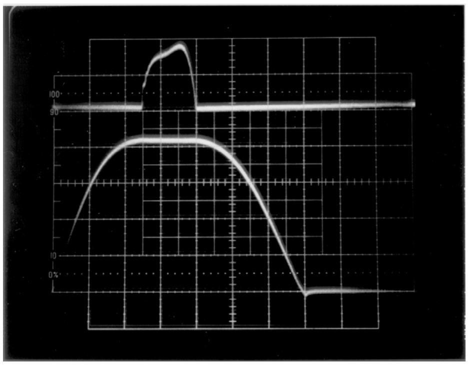

Figure 4.6: Magnet and active filter current at 33 kA
Upper trace: active filter current, 100 A/div,
Lower trace: magnet current, 10 kA/div, 0.5 ms/div.

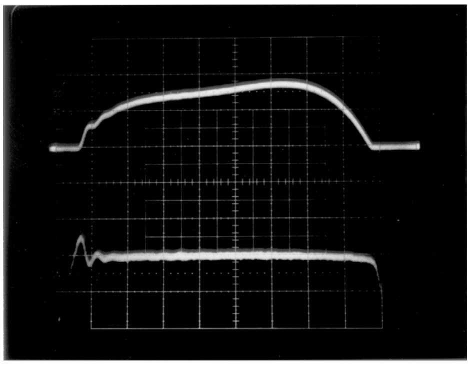

Figure 4.7: Zoom on flat top at 33 kA. The current flat-top precision is in the 10^{-4} range.
Upper trace: active filter current, 100 A/div,
Lower trace: magnet current, 40A/div, 0.1ms/div

The pulsed power supplies for the septum magnets completely fulfil the operational requirements: higher and repetitive currents for 1.4 GeV, pulse to pulse modulation, irregular pulsing and high reliability.

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