3.9 Power Supply System

The storage ring magnet power supply systems are rated for stable operation at a nominal energy of the stored electrons of 3 GeV. The system is designed with 10% operating margin and additional overhead for different subsystems to provide for flexible operation of the ring during the periods of installation, operation and the future. The power-supply system performance includes the specifications for providing the betatron tune shift (fine tuning) and modification to high values (low emittance option with horizontal betatron tune 14.22) as well as for beam position stabilization.
The power supplies provide three types of outputs

- Unipolar DC for the dipole, quadrupole, sextupole and septum magnets;
- Bipolar DC for the correctors;
- Pulsed power supply for the injection kickers.

The DC power supplies which feed the elements of the storage ring vary as to their power and output requirements.
The strictest demands are upon the dipole magnet power supplies. They must provide high stability level currents, of about ~600A, at full beam energy**.** In order to maintain the current regulation to necessary limits (0,2 $I_N \div 1{,}1\, I_N$; I_N is the nominal current at 3 GeV)**,** unipolar power supplies are used. Unipolar DC power supplies are also used for the quadrupole and sextupole magnet power supply circuits.
The corrector magnets require the usage of bipolar DC power supply sources. To provide the required level of current and reversing its direction if necessary.
The other type of power supplies are pulsed which are used for the injection system.

3.9.1 Dipole Magnets Power Supply

The storage ring consists of 32 gradient bending dipole magnets. Parameters of these magnets are listed in Table3.9.1.

Table 3.9.1 Parameters of dipole magnets.

Number of magnets	32
Current, A	574
Current density, A/mm^2	4.35
Voltage drop/Magnet, V	23.6
Voltage drop/String, V	755
Power/Magnet, kW	13.55
Power/String, kW	435

All storage ring dipole magnets are electrically connected series, and are powered by a single power supply. The block-scheme is shown in Fig. 3.9.1.

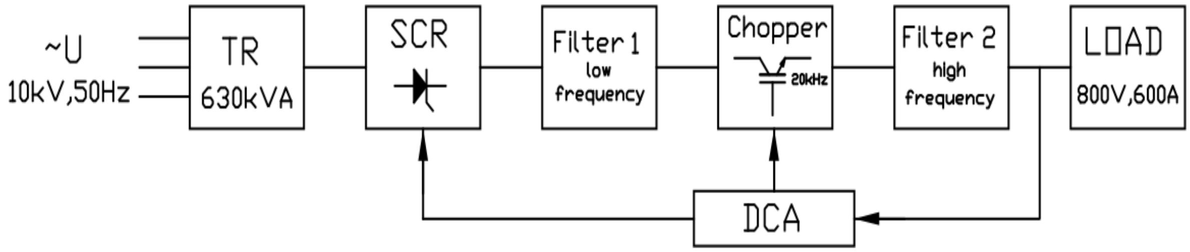

Fig. 3.9.1 The power supply scheme for the 32 dipoles.

The source must provide an output current of 580A. With 32 magnets in the ring and a voltage drop for each magnet's winding of 23.6V, the supply need to provide an output voltage of 755V.
Taking into account the losses and the efficiency of the converter with load, the power supply parameters are designed as:

- Nominal voltage – 800 V
- Nominal current – 600 A

The power supply block-diagram for {800 V, 600 A} power supplies is shown in Fig. 3.9.2.

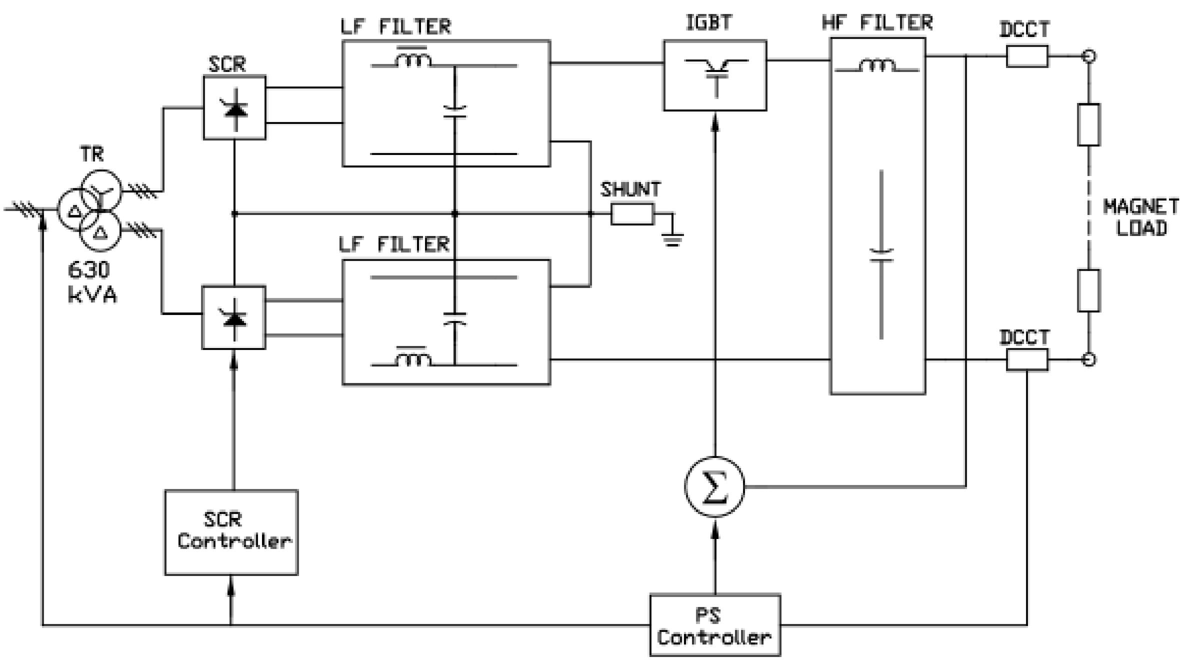

Fig.3.9.2 The block diagram of dipoles power supply.

As seen from the diagram, the power supply of the rectifier is carried out using a 3 winding transformer (TR) whose target windings are connected in wye delta connection modes. This results in a six-phase power supply for the rectifier which essentially decreases

pulsations of the rectified voltage. The controlled rectifier itself represents two series connected SCRs that are grounded at the center of their connection. This enables at a target voltage 800V calculate isolation and a class on SCR voltage on 400V. Also this keeps the string voltage symmetrical with respect to ground [1].
High frequency (LC) and low frequency filters reduce the DC voltage ripple. The output current is regulated and controlled by the chopper (on an IGBT basis) [2]. A pair of independent current transductors monitors the magnet current with one transductor belonging to the external current regulation loop. The other transductor verifies that the magnet current is correct.
The 600A supply-current rating requires two parallel-connected current-sharing IGBT’s. A low frequency LC filter compensates for line voltage variations.
Thus the power supply capacity is about 600kVA and is situated in a separate location, in a protected compartment. The SCR block is mounted on T453-800 SCR basis, and has a voltage class of 14**.** The water cooling of SCR-s is assumed [3]**.**
The dipole magnets power supply circuit diagram is shown in Fig.3.9.3.
The power supply consists of

- a six-phase transformer,
- a 12-pulse SCR rectifier,
- a low frequency LC filter,
- an IGBT (Insulated-Gate-Bipolar-Transistor) chopper converter, and
- a high-frequency output filter.

Besides the mentioned basic elements, a large number of auxiliary devices are included in the power source. Those are the special switching on/off circuits, circuits which regulate the operation of both: the entire power supply and it’s separate parts, circuits for protection from possible overload, insulation control devices, devices which program the source operation, etc. The use of constant current transistors as adjustable elements is appropriate, sice this device has low-inertia and is controlled by electric signals. The feedback signal is obtained from the stabilizers outlet and is amplified in the DC amplifier (DCA), where it affects the adjusting resistance – transistor.

The inclusion of feedback into the stabilizer results in an improvement of the external characteristics, with dynamic range and high stability of the output current. The stabilizers feedback circuit includes elements, which help in the measurement of the value of the output voltage deviation from the desired stabilization level.
The stabilizer is made of two IGBT transistors, placed in parallel with the line current of 600A being distributed between these transistors. The transistors operate in a switching mode with switching frequency equal to 20kHz. This frequency is enough to reduce 600Hz pulsations. In order to smooth the pulsations caused by the switch’s commutator, the filters L2, C3 are included in the power circuit of the stabilizer [4].
For an energy upgrade of the storage ring to 3.2 GeV, the parameters of the power supply would be correspondingly modified as: available capacity- 480kW, rated output current- 600A, rated output voltage- 800V.

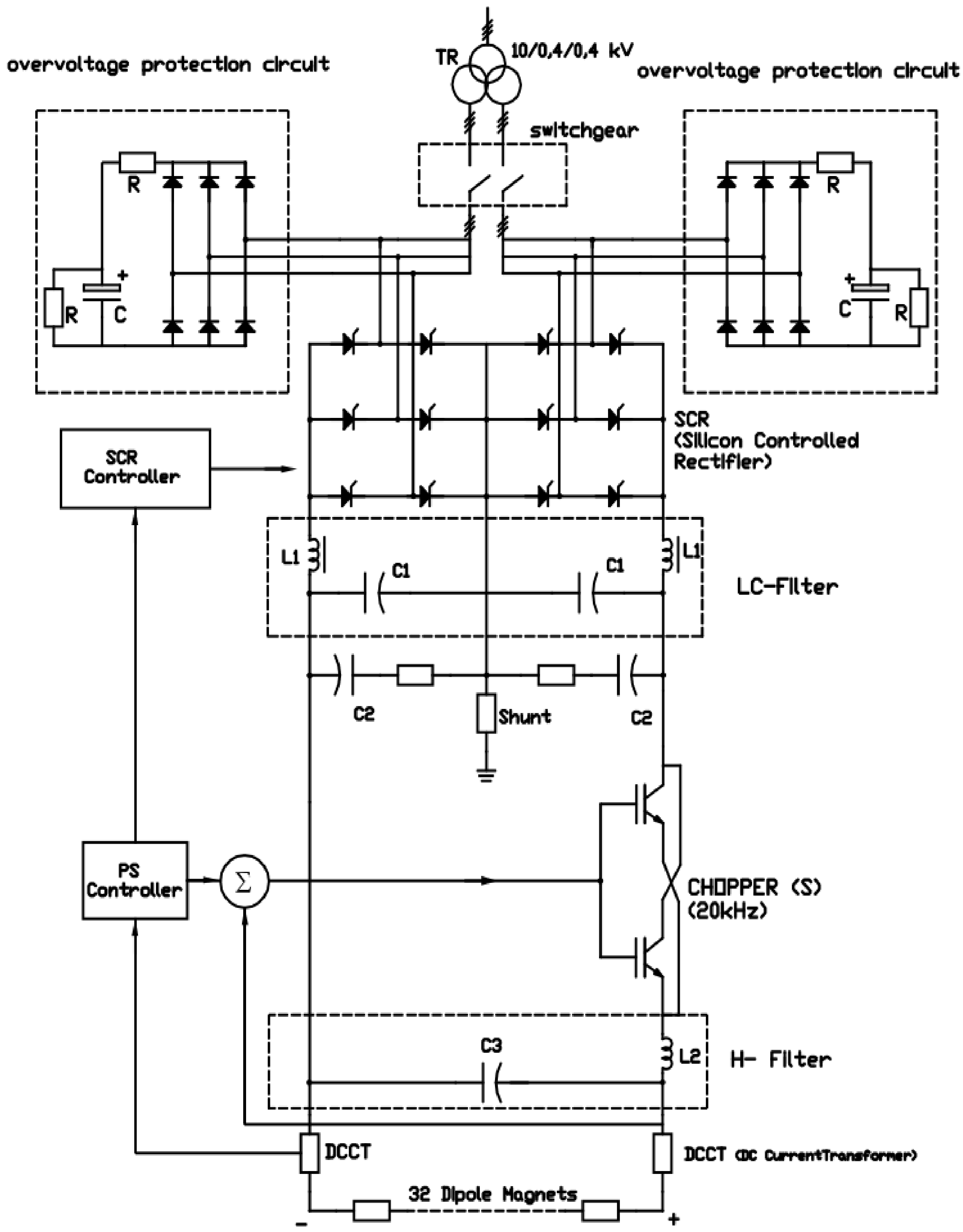

Fig. 3.9.3 Dipole magnets power supply circuit diagram.

3.9.2 Quadrupole Magnets Power Supply

The parameters of the quadrupole magnets is given in Table 3.9.2

Table 3.9.2 Quadrupole magnets parameters

	QF	QD	QFC
Quantity	32	32	16
Current, A	82	64	84
Voltage, V	50.5	26.39	40.8
Magnet power, kW	4.15	1.7	3.5
Series connected groups	4	2	2
Magnets per group	8	16	8
Group voltage, V	404	423	326.4
Group power, kW	34	27.2	27.5
Power supply capacity, kW	50	50	50
Power supply quantity	4	2	2

The quadrupole magnet power supply source is represented as a DC voltage pulse rectifier. From power supply to load, the power transfer process is regulated by IGBTs (Isolated-Gate-Bipolar-Transistor). As shown in diagram 3.9.4, the elements of the circuit are: choke, capacitor, transformer and controlled chopper. Feedback circuits allow for the regulation of the output current value and current stabilization to a level of $\Delta I / I = 10^{-4}$. The main LC filter reduces the DC voltage ripple. This power supply is unipolar and consists of a 4-cycle chopper-converter with a breaking frequency of 20 kHz. QF, QD, QFC quadrupole magnets are connected in two series connected circuits.

Each circuit is powered by a single DC current, unipolar power supply, resulting in a total of 12 series circuits. The power source is carried out as a DC pulsed rectifier, shown schematically in Fig. 3.9.4.

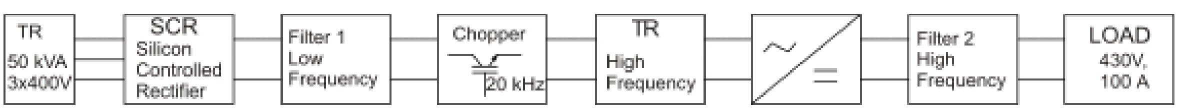

Fig.3.9.4 Quadrupole magnet power supply block-diagram

The power supply is operated out as 2-cycle chopper with a switching frequency of 20kHz. At the rectifier's (SCR) output, a low-frequency filter (filter 1), reduces rectified voltage pulsations. After filter 1, the voltage is delivered to a 2-cycle DC rectifier (Chopper), where output is a high frequency AC voltage. This makes it possible to reduce dimensions of the high frequency transformer and filter (filter 2). The quadrupole magnets power supply circuit diagram is shown schematically in Fig.3.9.5.

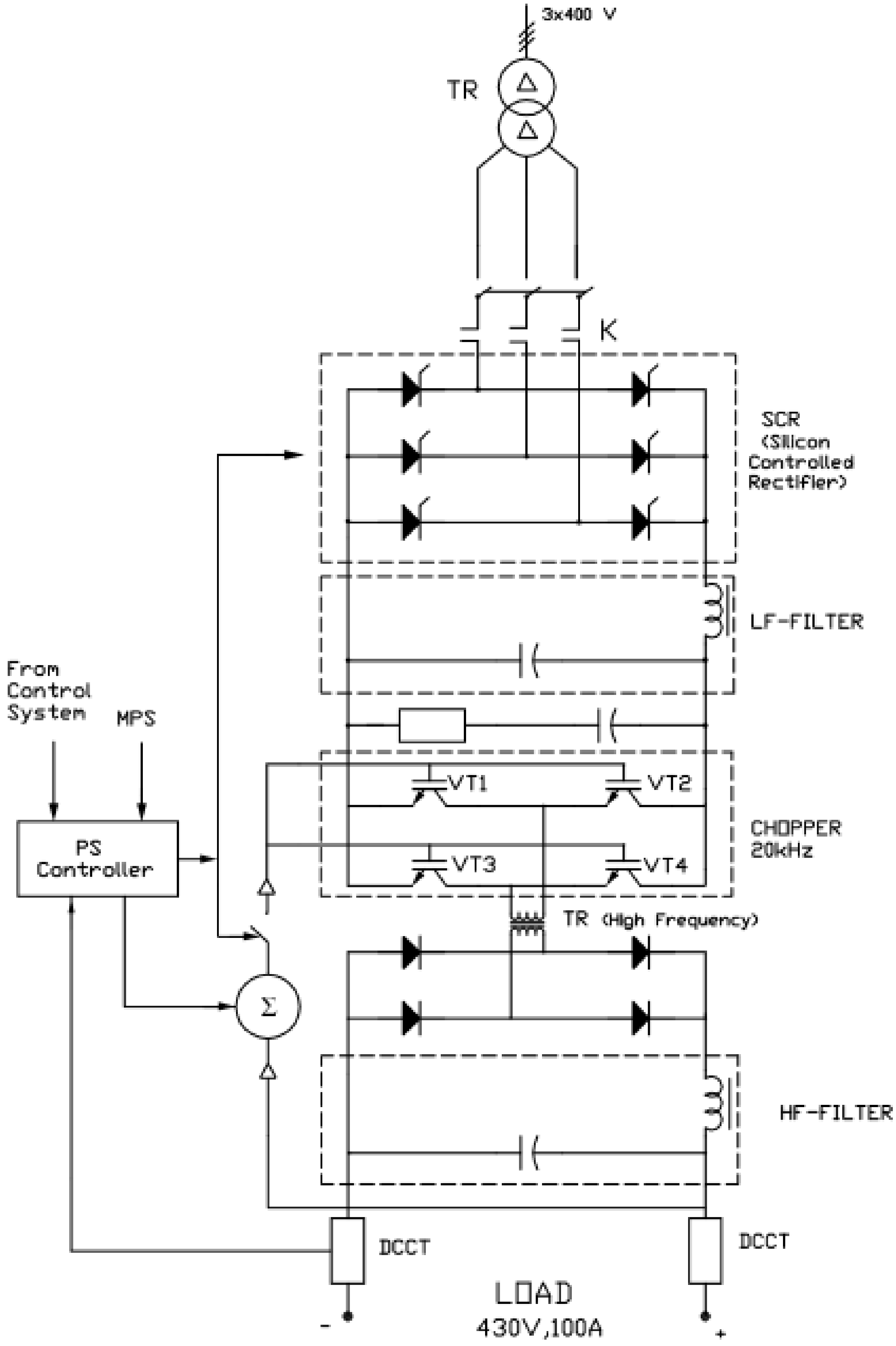

Fig.3.9.5 Quadrupole magnets power supply circuit diagram.

The chopper represents an inverter that converts a direct current into a high frequency current with the inverter being a bridge circuit of 4 IGBT's (Isolated Gate Bipolar Transistor). Generation of the AC voltage on the high frequency transformer's primary winding occurs form a ping-pong initiation of IGBTs: VT1, VT3 and VT2, VT4.

For all the quadrupole magnets (QFC, QF, QD) 8 identical power supply sources are used, each with a capacity of 50 kVA. The above mentioned power supplies are located in separated racks.

3.9.3 Sextupole Magnet Power Supply

The storage ring's sextupole magnets are divided into 2 families: SF and SD. Each family consists of 32 magnets. Each SF and SD family is connected in series, and is fed from an individual silicon controlled rectifier (SCR). The magnets parameters are listed in Table 3.9.3

Table 3.9.3 Parameters for Sextupole magnets

Name	SF	SD
Quantity	32	32
Current, A	111	133
Voltage, V	9.1	11.9
Magnet power, kW	1.02	1.6
Series connected groups	1	1
Magnets per group	32	32
String voltage, V	292	381
String power, kW	33	52

As is shown in the table above, the maximum power capacity for the SD magnet group is 52 kW supplied at a voltage of 381V.The sextupole magnet power supply system design is based on the scheme similar to that of quadrupoles as shown in Fig. 3.9.4 and Fig. 3.9.5, with output parameters: U_N=400V, I_N=150A, P=60kW.

3.9.4 Corrector Magnets

A modern SL source requires a high degree of flexibility, for both static and dynamic corrections, in the beam steering system. Because the design of sextupoles capable of delivering the required field does not present significant engineering difficulties, the sextupoles are equipped by additional bi-polar coils to generate fields for horizontal and vertical correction. Additionally separate horizontal and vertical corrector dipoles will be used. In total there are 32 corrector dipole magnets spaces in the storage ring. The corrector magnet parameters are listed in Table 3.9.4.

Table 3.9.4 Parameters of corrector magnets

C-shaped corrector elements		
Steering	**Horizontal (H)**	**Vertical (V)**
Number of magnets	32	32
Magnetic length (m)	0.2687	0.2687
Magnetic field (T)	0.0614	0.0409
Conductor width (mm)	4.93	4.93
Conductor height (mm)	1.8	1.8
Conductor cross section area (mm^2)	8.88	8.88
Coil/magnet	1	2
Turns per coil	120	240
Amp. Turns per coil (A)	2656	5004
Current (A)	22.13	20.85
Current density (A/mm^2)	2.5	2.3
Power/magnet (W)	170	302
Voltage drop/magnet (V)	7.68	14.47

The correction dipole magnets have separate windings for horizontal and vertical correction with each of the windings being powered by a standard bipolar power supply, rated at 50V, 30A. These are same type of power supply need in feeding the sextupole magnet windings. The correction magnet power supply principal diagram is shown in Fig.3.9.6 and includes the low frequency (LF) filter, converter and high frequency (HF) filter. These standard bipolar power supplies are fed from a bulk power supply

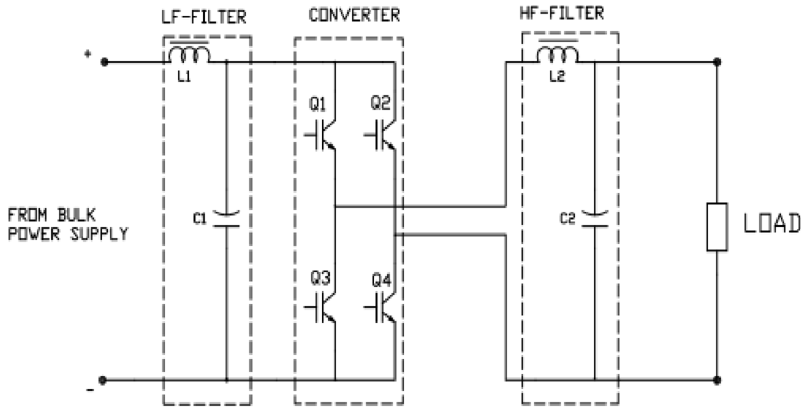

Fig.3.9.6 The correction magnet power supply principal diagram.

3.9.5 Pulsed Magnets Power Supply

The septum and kicker magnets of the booster and storage ring provide the injection and the extraction of the electron beam and basically have pulsed power supply to generate the required magnetic field within the injection/extraction duration. The shape and the width of the pulses depend on the specific function of each magnet. The repetition frequency of the pulse is 2 Hz. The injection in the booster is via the thick septum and the full-aperture fast kicker magnet. Current pulse forms for septum and bumper magnets must be close to half-sine, the kicker magnet current pulse form must have flat-top. The specifications of the pulsed magnets are given in Table 3.9.5.

Table 3.9.5 Parameters of the septum and kicker magnets.

Type of Magnet	Magnetic Field	Current Waveform	Duration	Quantity	I_{peak}, A
Booster injection septum	0.288T	Half-sine wave	25µs	1	4430A
Booster injection kicker	6.9mT	trapezoidal	150/480/150ns	1	212A
Booster ejection thin septum	0.436T	Half-sine wave	25µs	1	2627A
Booster ejection thick septum	0.635T	Half-sine wave	25µs	1	3913A
Booster ejection bumpers	48/20/78/mT			3	272A
Booster ejection kicker	13.4mT	trapezoidal	150/480/150ns	1	140A
SR injection thin septum	1.01T	Half-sine wave	25µs	1	4821A
SR injection thick septum	1.14T	Half-sine wave	25µs	1	5430A
SR injection kicker	0.3	Half-sine	25µs	4	3597A

Good key features of the thyristors allow the successful usage of power impulses in the schemes of generators. Pulsed magnets power supply is fulfilled according to basic principles of impulse generators construction (Fig. 3.9.7).

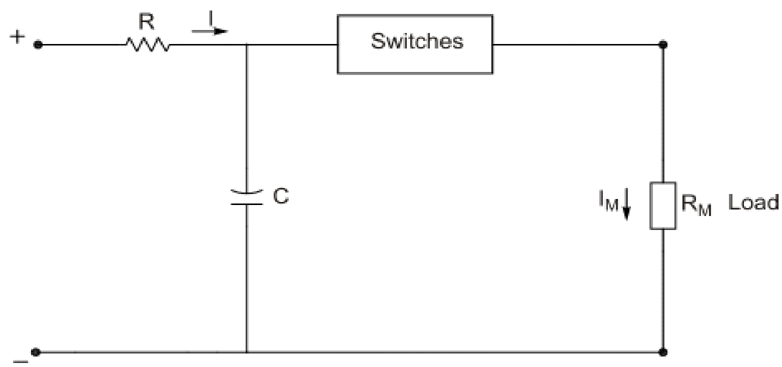

Fig. 3.9.7 The pulse generator general scheme.

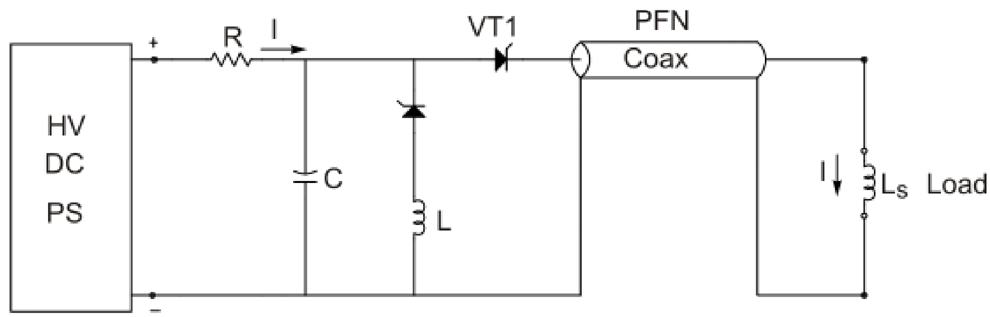

Fig. 3.9.8 The septum magnet power supply principal scheme.

The switching device (Switches) discharges the capacitor (C) via the load (R_M). The septum magnet pulsed power supply principal scheme based on the above-mentioned scheme is shown in Fig. 3.9.8. Output pulse duration depends on C L_S series connected, resonant circuit parameters, including coax cable impedance (Z), which forms the impulses [5]. The scheme consists of:

- High Voltage DC Power Supply
- Charging resistance (R)
- Capacity (C)
- Energy recovery choke
- Pulse forming network (PFN).

When the VT1 thyristor is closed, the C capacitor is charged via R load resistance practically up to U_n voltage of the power supply. The generator remains in such stable state until the VT1 thyristor is switched off. After when the thyristor is switched on by admission impulse, the duration of which must be less than the outlet impulse duration (t_i), the current I_i, which depends on voltage of power supply U_i and on the parameters of the discharge circuit, starts passing through the septum's winding. Simultaneously the current I_k occurs, which is conditioned by compensator discharge through the septum's winding and the open thyristor. This current has a sinusoidal form and U_n/Z amplitude, where Z is the impedance of the circuit. Parameters of the generator and its capacity are calculated according to the duration and amplitude of the impulse [6]. The current impulses of kicker magnets are trapezoidal. To provide a flat top of the impulse, a capacity multiplication scheme adopting a saturated reactor in a discharge circuit, is used. Coaxial cables in discharge circuits provide the necessary duration of the impulses, because it depends on the value of the Z impedance of the coaxial cable. The scheme of the kicker magnet power supply is given in Fig. 3.9.9. This power supply allows to obtain impulses of different amplitudes [7].

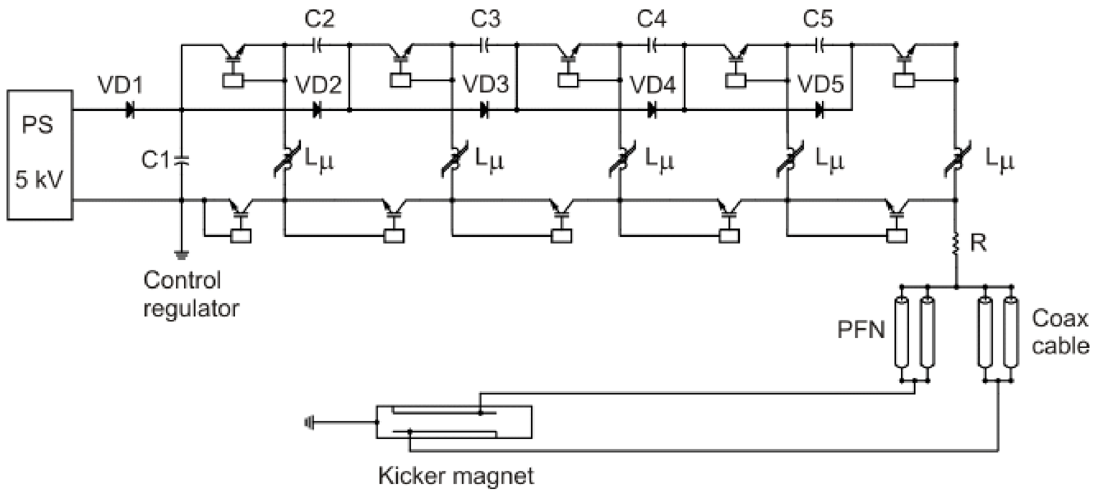

Fig. 3.9.9 Kicker magnet power supply scheme.

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