THE CERN ACCELERATOR SCHOOL

Different power supplies for different machines

Hans-Jörg Eckoldt
DESY

Warrington, UK

17.05.04

Congratulation

for having chosen

POWER ELECTRONICS

Power electronics needs the knowledge of

- Power electronic devices
- Mains behavior
- Regulation theory
- High precision measurement
- Mechanical capabilities
- Analog circuit technology
- Digital circuit technology
- Control system
- Statistics for large number of systems
- Databases
- Cooling technology
- Programming e.g. Internet, FPGAs, DSPs, PLCs
- Simulation tools
  - Missing RF, but with switched mode power supplies we are working on this

Sorry!

- Please be not disappointed, if your very interesting power supply is not mentioned here

- Due to the large number it is not possible

Structure of the seminar

- Cycling machines
- Fast ramping machines
- Slow ramping machines
- Pulsed machines
  - Magnet Power Supply
  - Constant power power supply

Cycling Machines

- DESY II, Hamburg
- ESRF, Grenoble
- BESSY II; Berlin
- SLS, Villingen

- Operation at frequencies between 0.3 and some 10 Hz
- Special care has to be taken for the flicker frequencies

Disturbances to the mains

The amount of allowed disturbances is defined in the German standard VDE 0838, IEC 38 or the equivalent European standard EN 61000.

No energy consumer is allowed to produce more distortions than 3% of the voltage variation of the mains.

For low frequencies in the visual spectrum this value is even more restricted. The low frequencies are called flicker frequencies. The human eye is very sensitive to changes in light intensities in this frequency domain.

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Allowed disturbancies to the grid according to IEC 38/VDE 0838

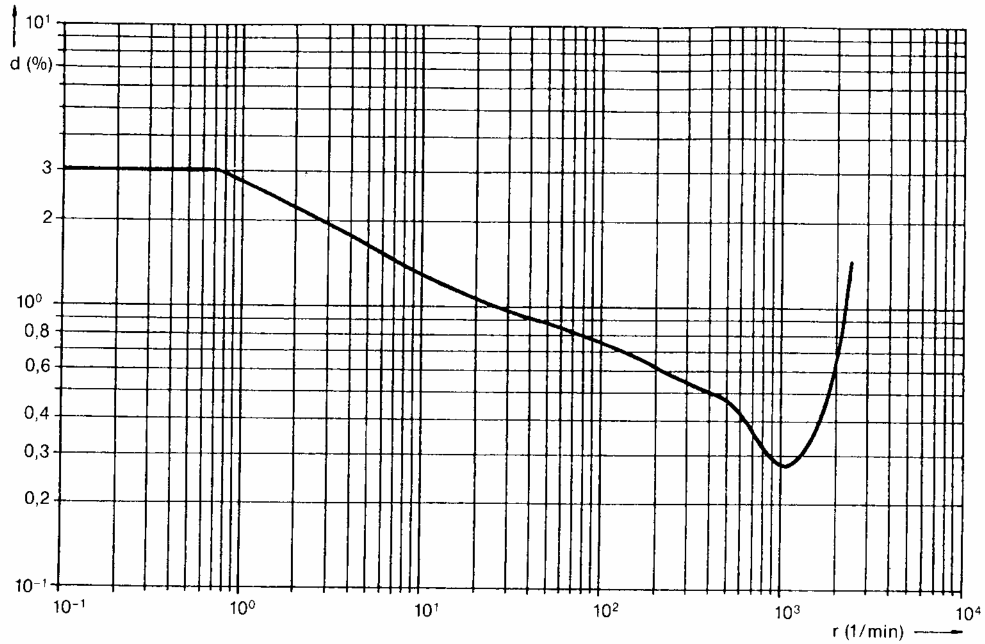
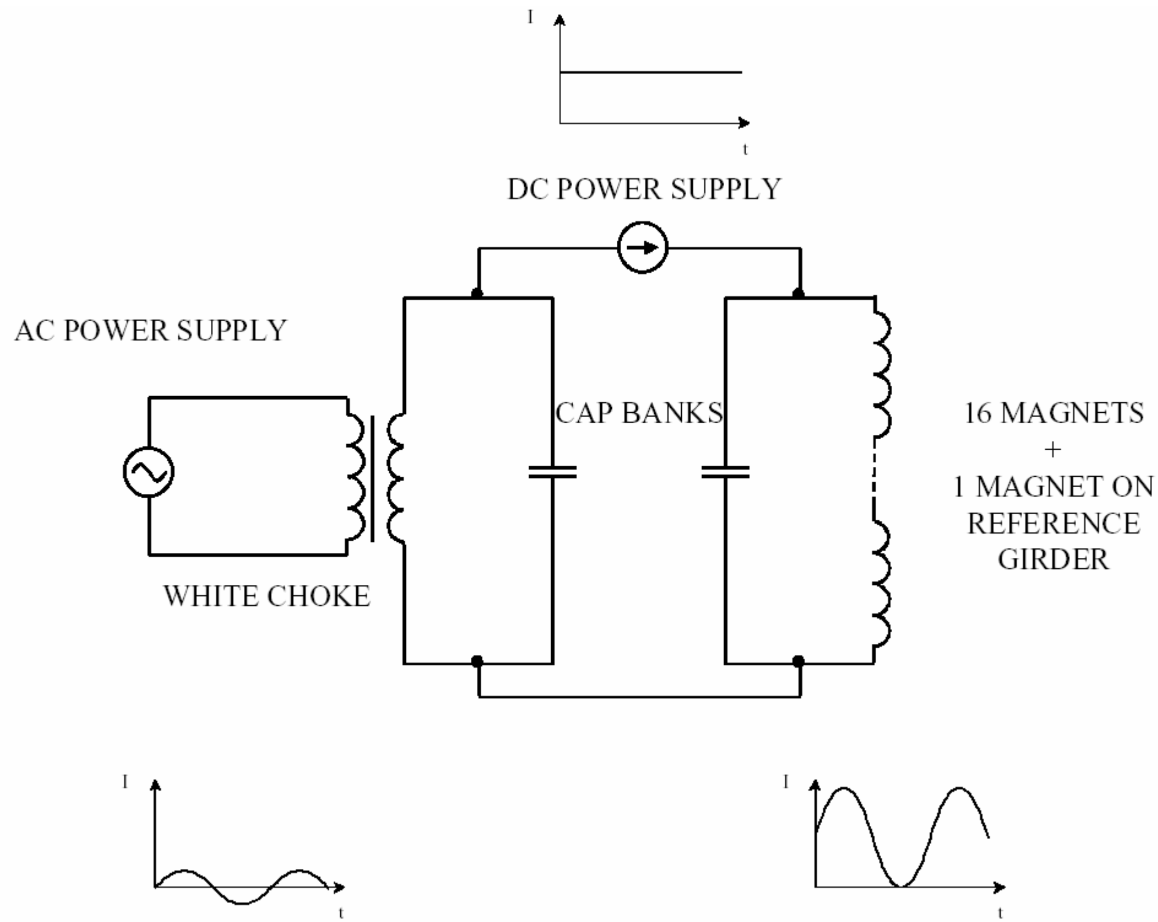


Bild 5-2: Verträglichkeitspegel für regelmäßige rechteckförmige Spannungsänderungen

White circuit



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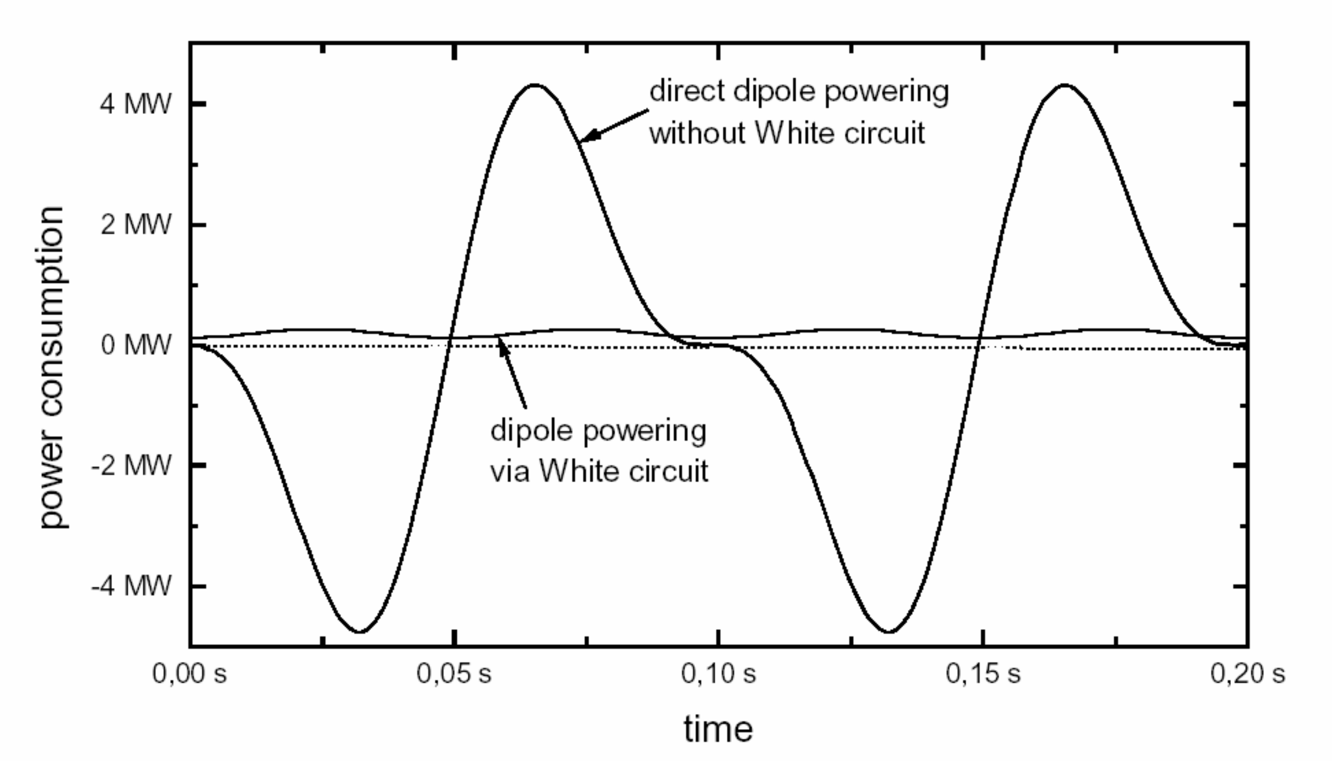
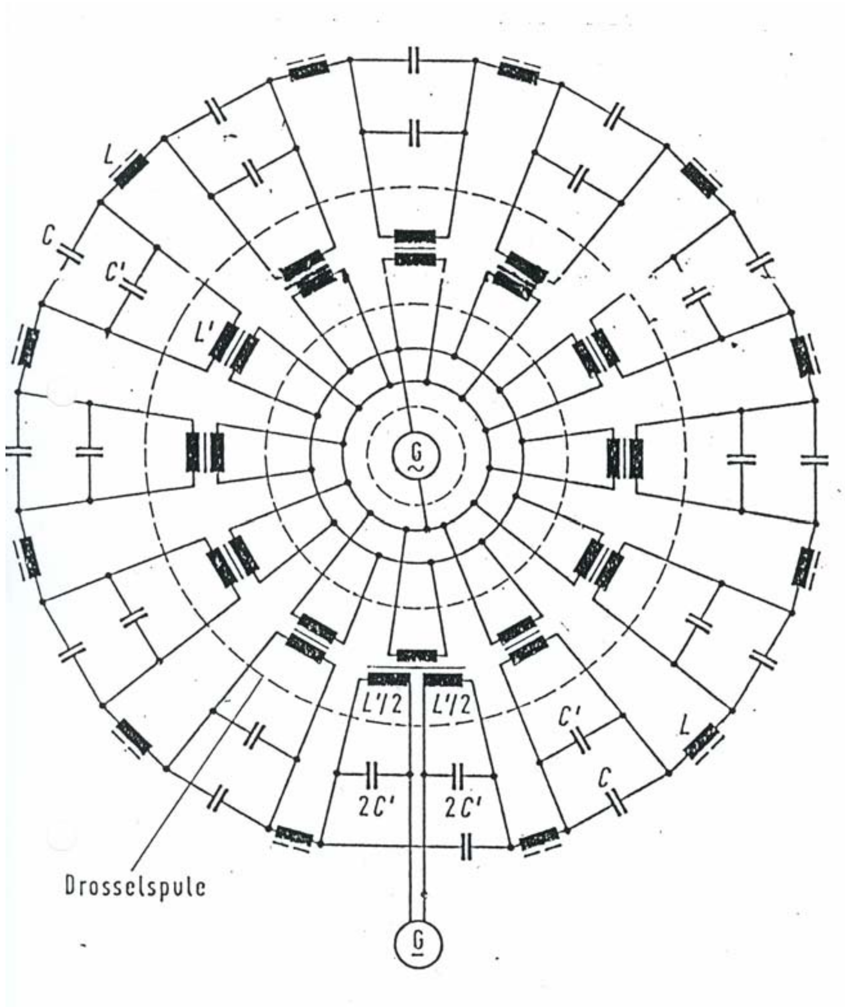
Calculated Power with and without White circuit for BESSY II



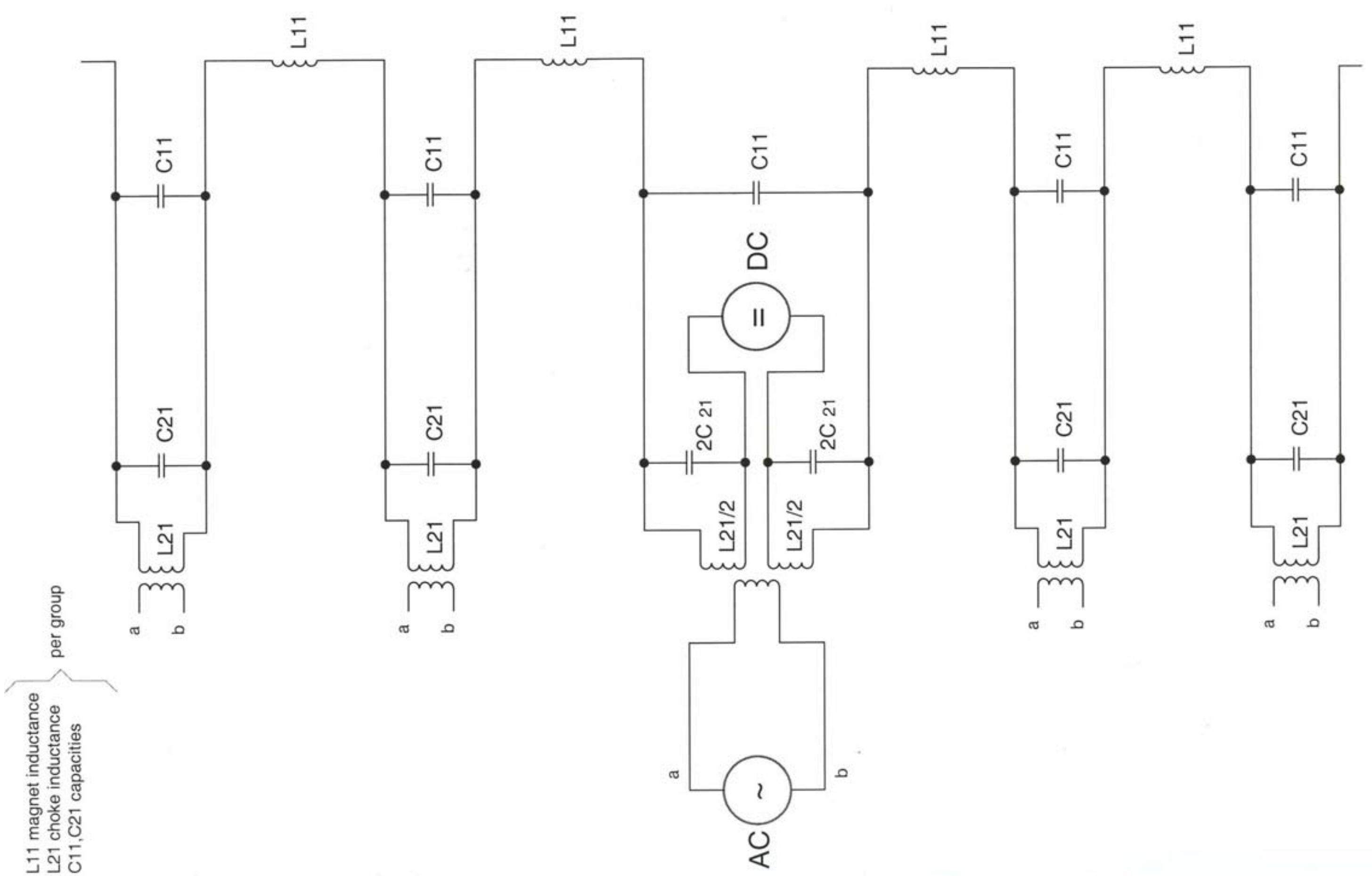
DESY II
4.5 GeV, 7 GeV, 10 GeV max.

	Dipole	QP	SP
I_{max}	1170 A	1530 A	530 A
$I_{rms\ magnet}$	873 A	940 A	324 A
$U_{rms\ Choke/magnet}$	4.3 kV * 12 51.6 kV	3.34 kV	273 V
$I_{DC\ PS}$	585 A	765 A	255 A
$U_{DC\ PS}$	27.7 V	122.4 V	32 V
$I_{AC\ PS}$	665 A	540 A	187 A
$U_{AC\ PS}$	990 V	3.22 kV	273 V

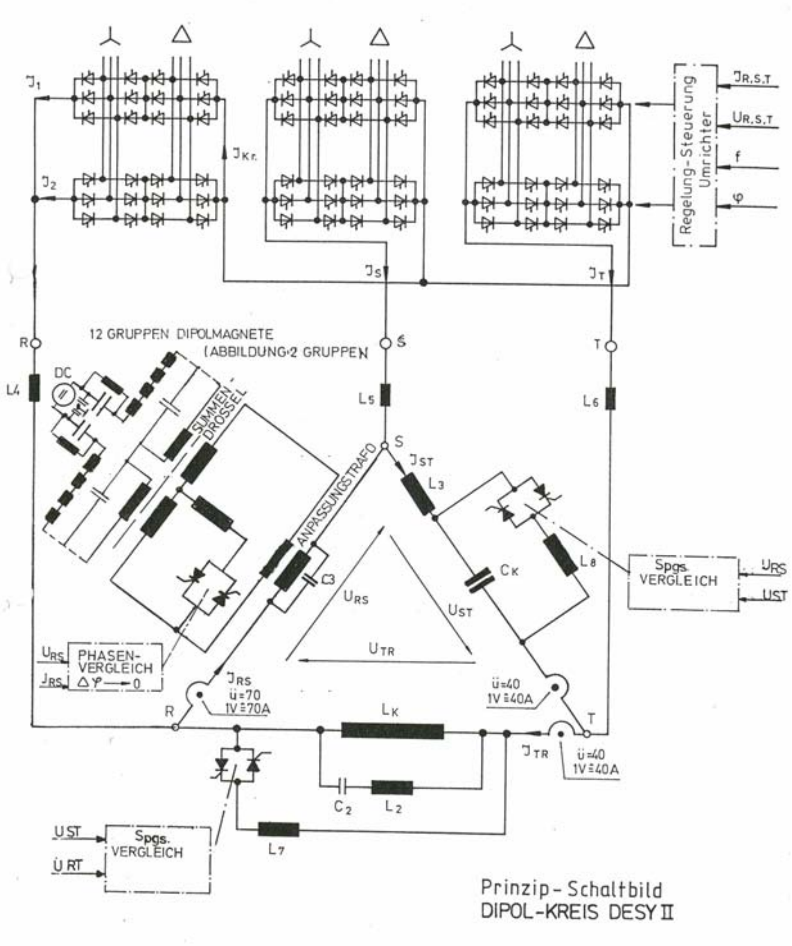
DESY II Overview (artist view)



DESY II with compound inductor (White choke)



DESY II dipole power supply with Steinmetz circuit



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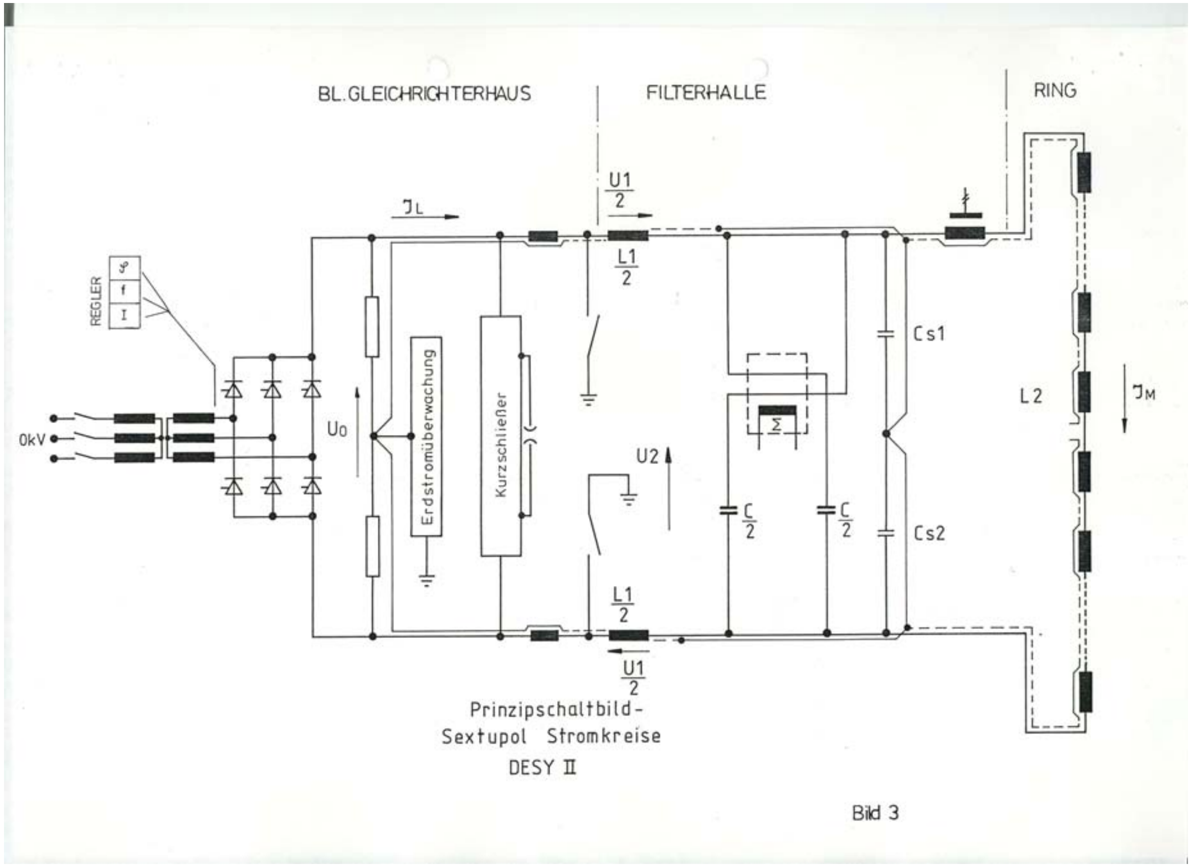
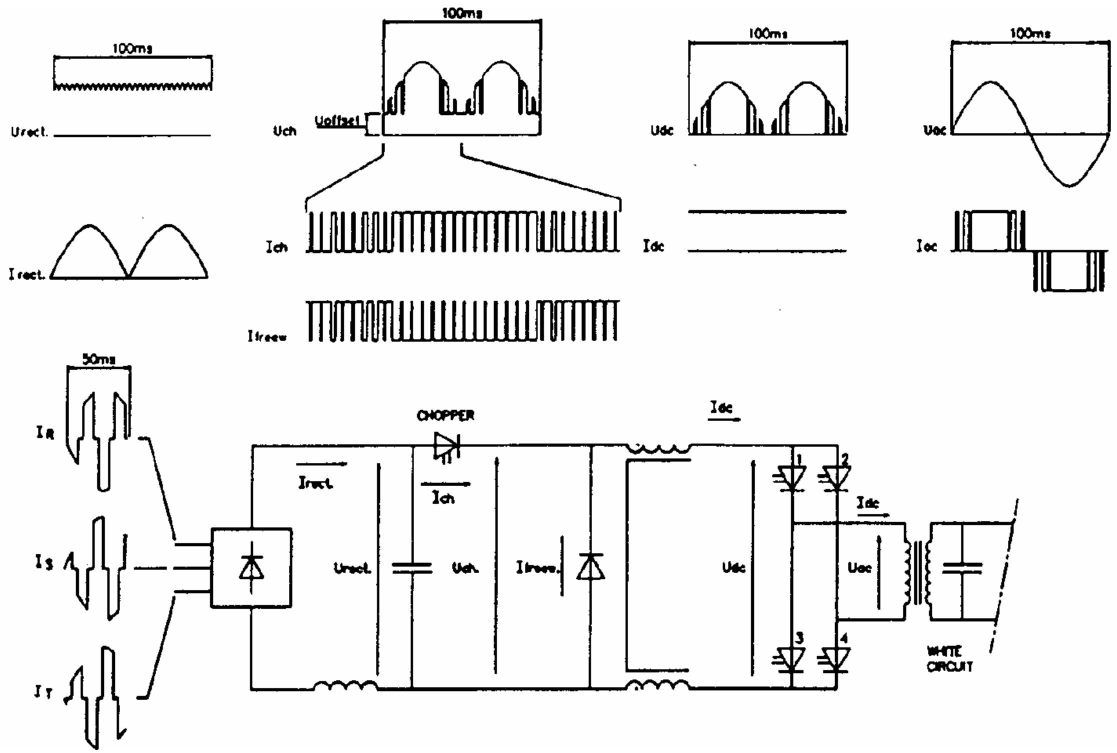
DESY QP, SP circuit



ESRF 6 GeV

	Dipole	QPF	QPDF
I_{max}	1500 A	500 A	500 A
$U_{rms\ Choke/magnet}$	11 kV	2 kV	2 V
$I_{DC\ PS}$	800 A	200 A	180 A
$U_{DC\ PS}$	600 V	200 V	200 V
$I_{AC\ PS}$	800 A	200 A	180 A
$U_{AC\ PS}$	V	V	V

Power supply of ESRF

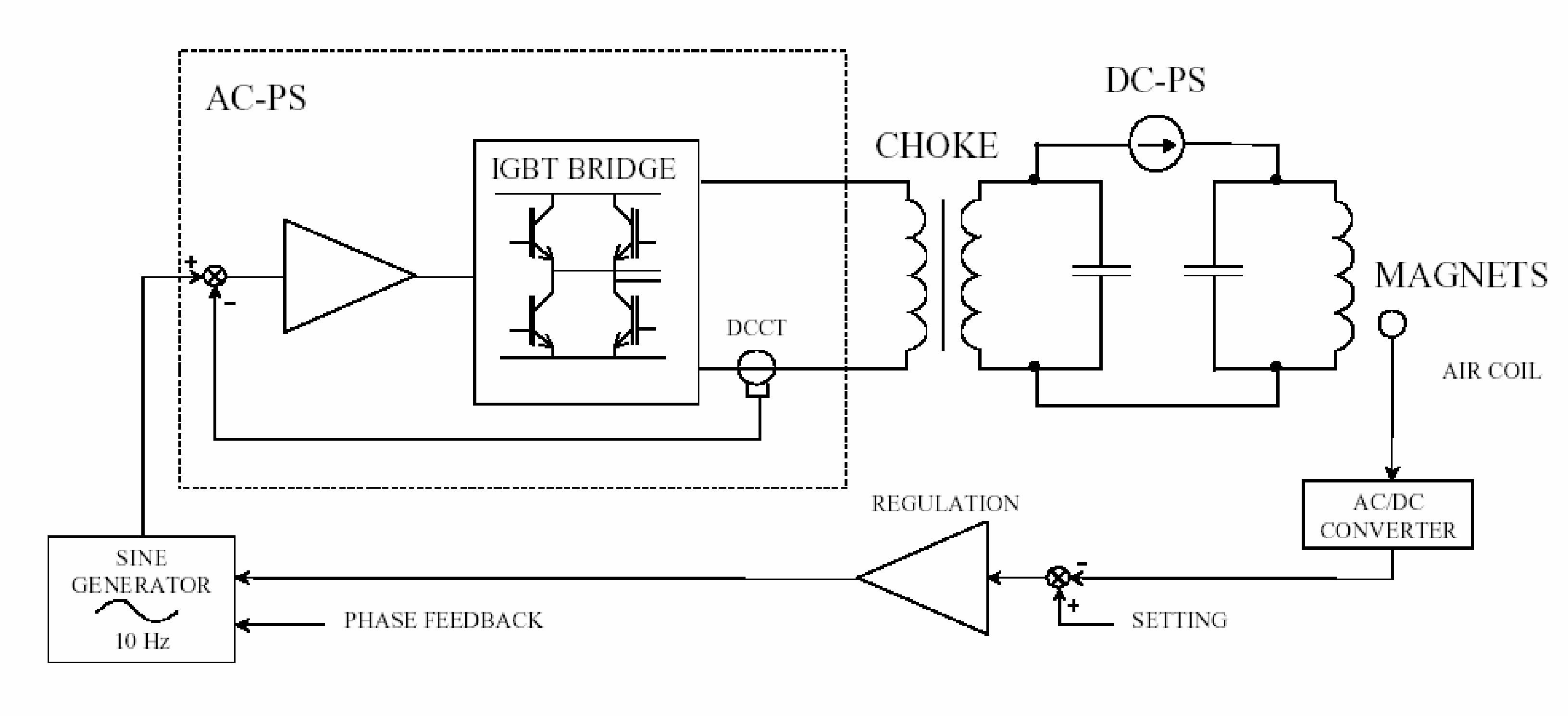


Rectifier circuit Chopper DC circuit Inverter

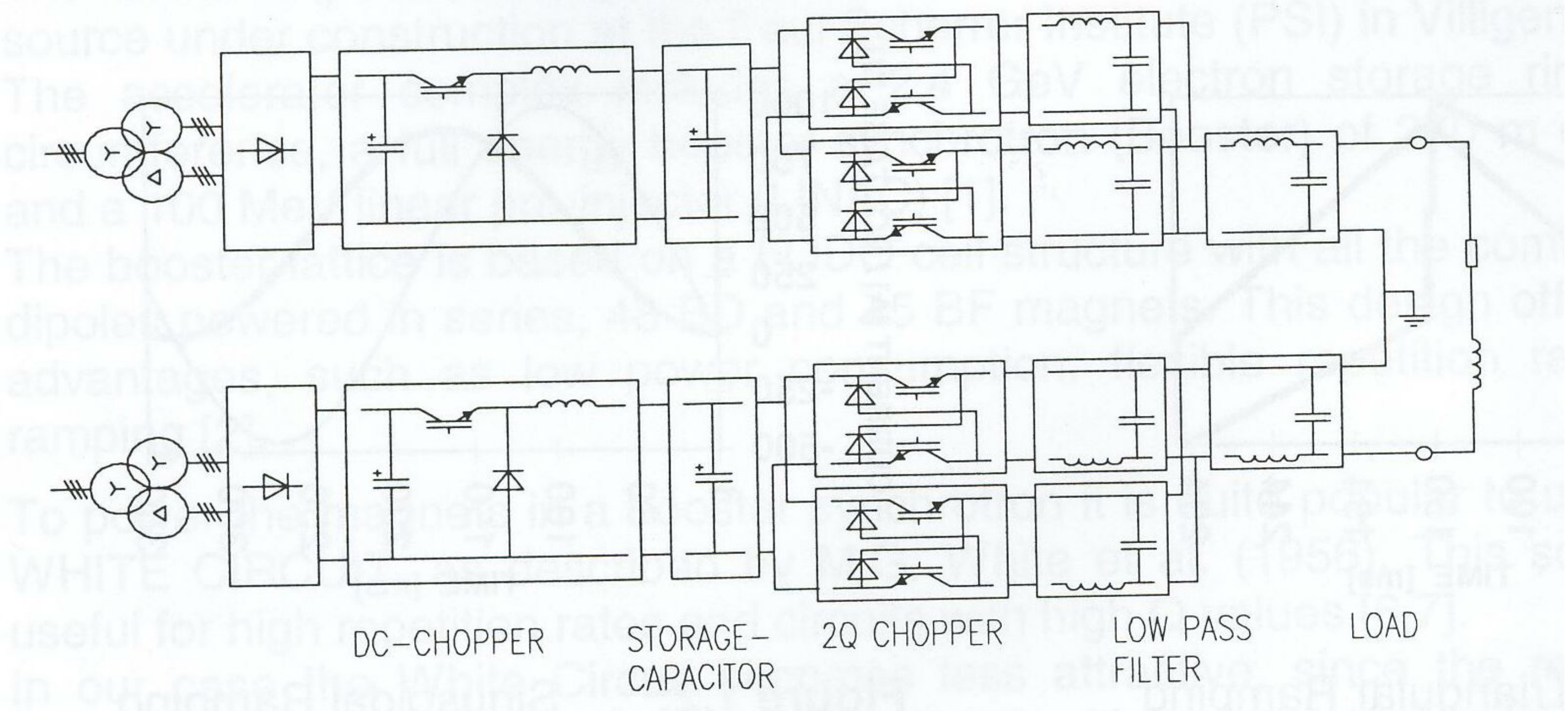
BESSY II 1.9 GeV

	Dipole	QPF	QPDF
I_{max}	2277 A	492 A	395 A
$U_{rms\ Choke/magnet}$	3112 kV	527 V	423V
$I_{DC\ PS}$	800 A	200 A	180 A
$U_{DC\ PS}$	120 V	70 V	70 V
$I_{AC\ PS}$	778 A	200 A	200 A
$U_{AC\ PS}$	311V	184 V	184 V

Schematic of the BESSY II Power supply



Power supply at SLS



Fast ramping machines

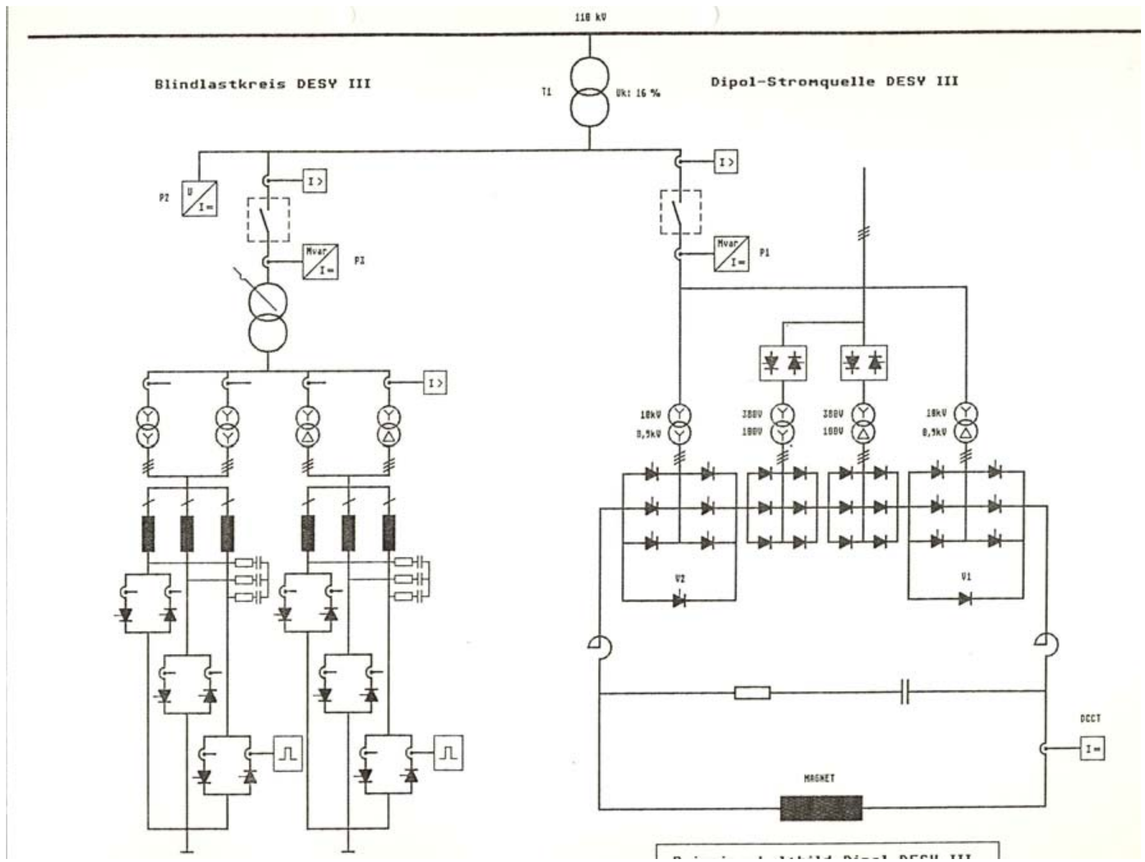
- DESY III
- Tevatron
- Fermilab Main Injector
- Cern Antiproton Decelerator
- PETRA

- Ramping times from a second to a minute
- $U=R*i + L*di/dt$
  Due to the inductance the term demands for a significant higher voltage than for steady state
- Negative voltage has to be applied for down ramping
- Precautions for the mains have to be taken

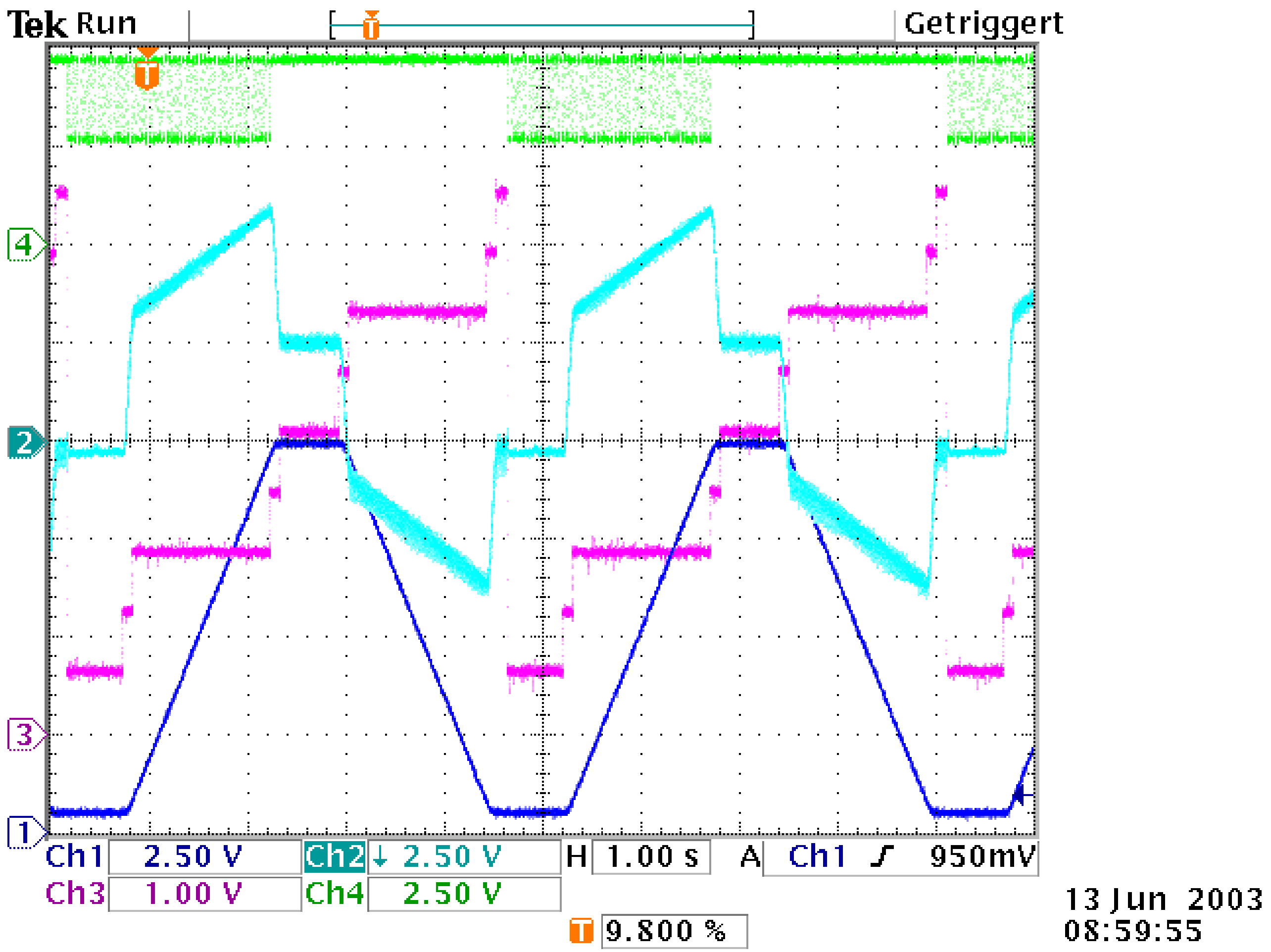
DESY III

	Dipole
$I_{\text{flat top}}$	1160 A
$U_{\text{flat top}}$	1 kV
$I_{\text{flat bottom}}$	50 A
$U_{\text{flat bottom}}$	42 V
di/dt	665 A/s
Ramping time	4 sec

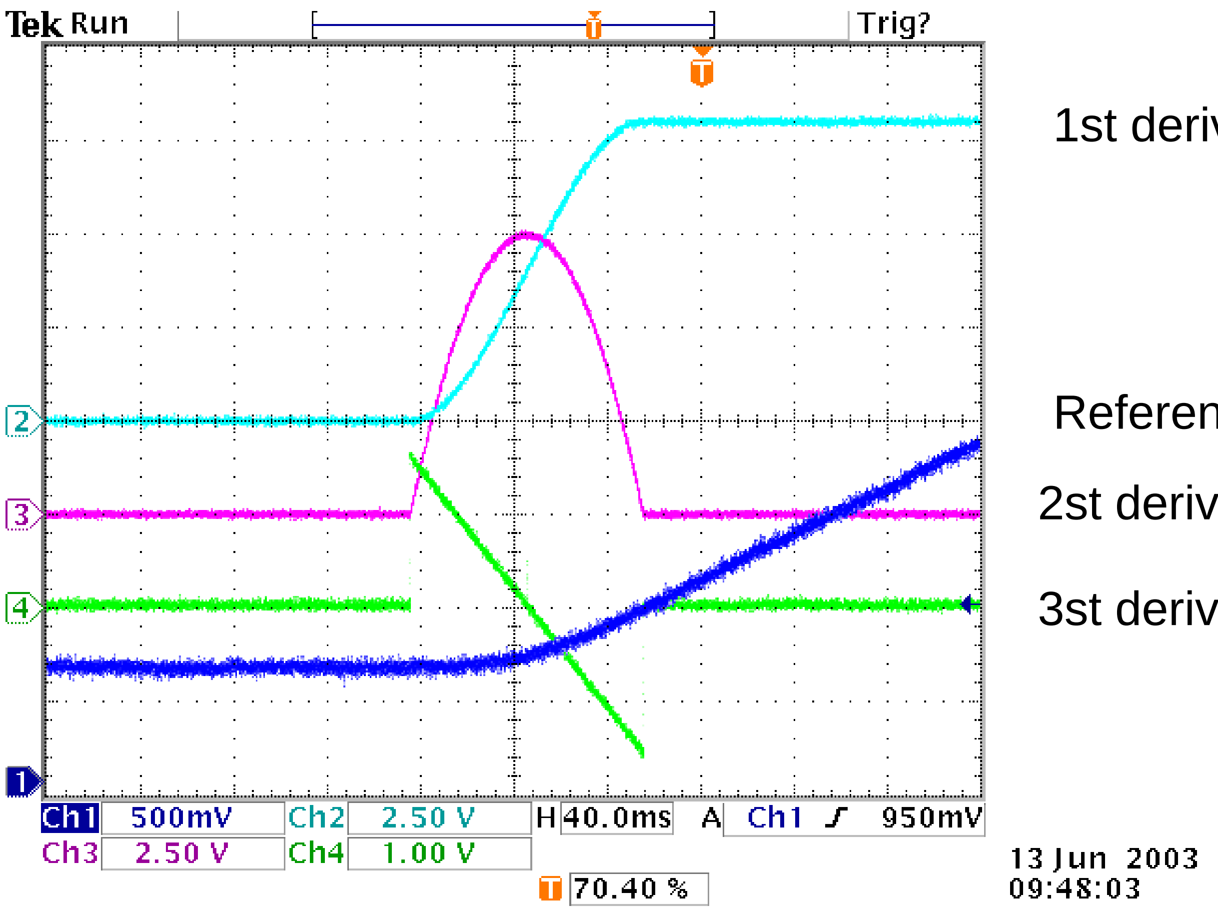
DESY III Power supply with dynamic reactive power compensation



Waveforms of DESY III



Signals for the DESY III ramp



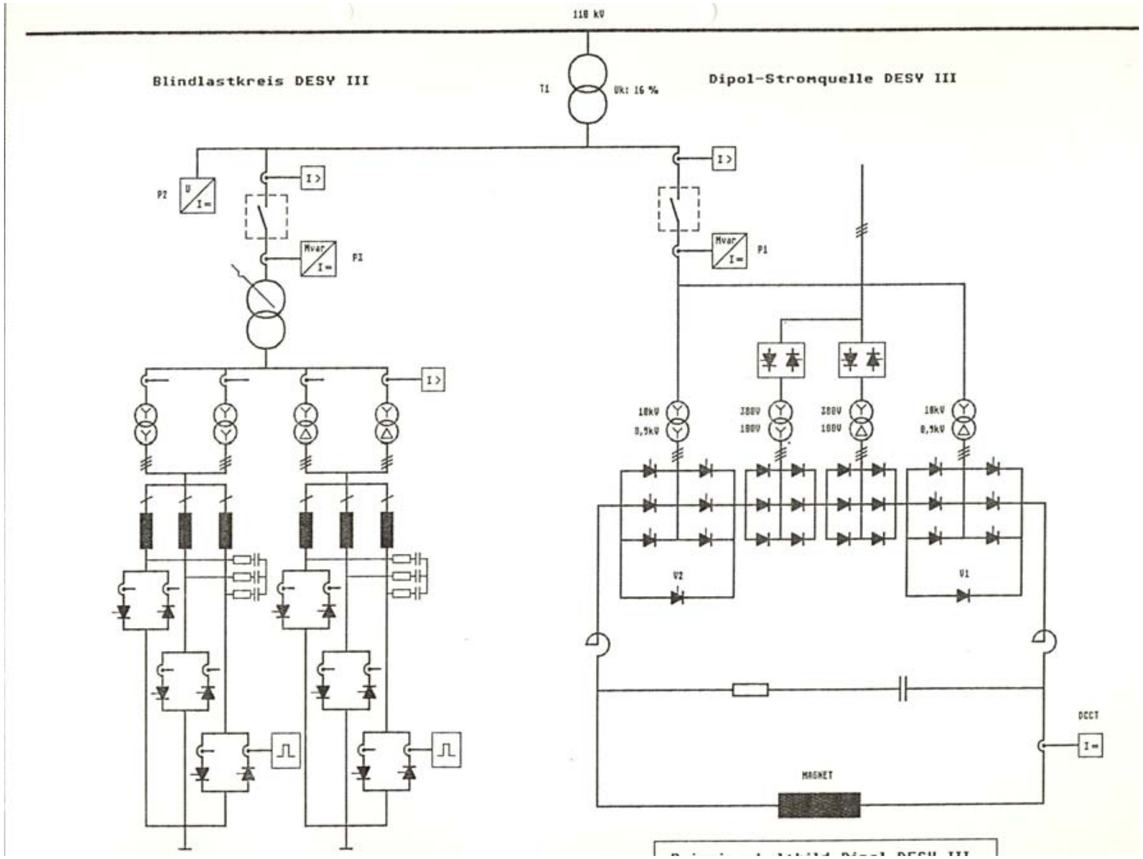
1st derivation

Reference value

2st derivation

3st derivation

DESY III Power supply with dynamic reactive power compensation

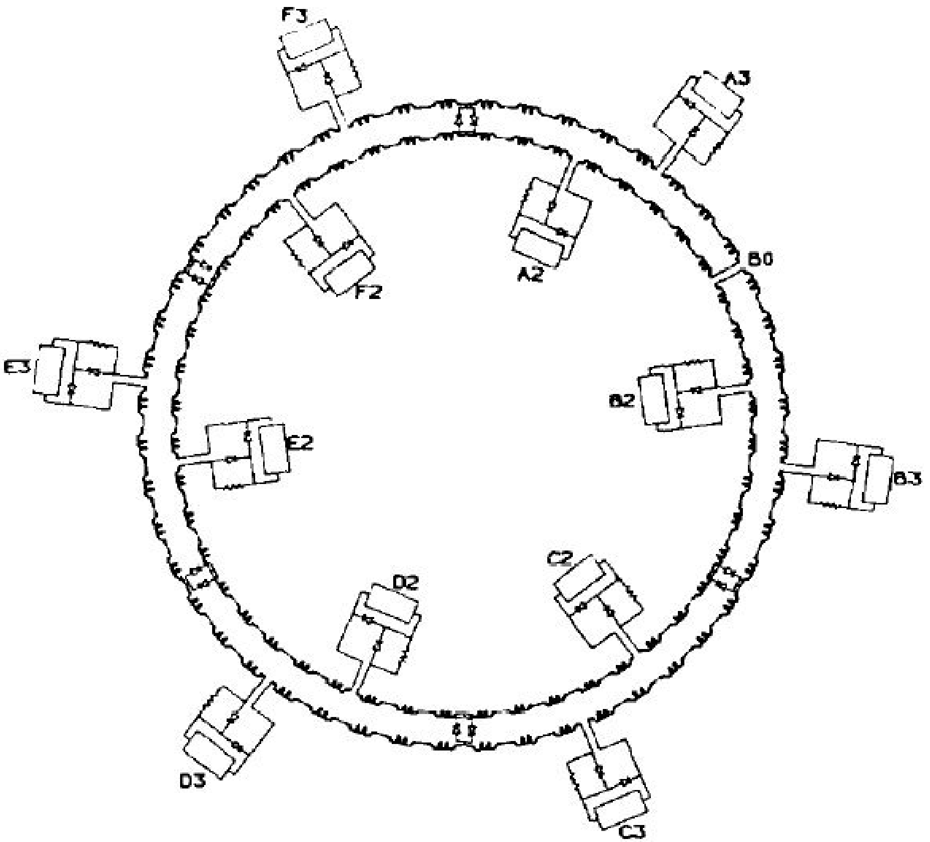


Tevatron

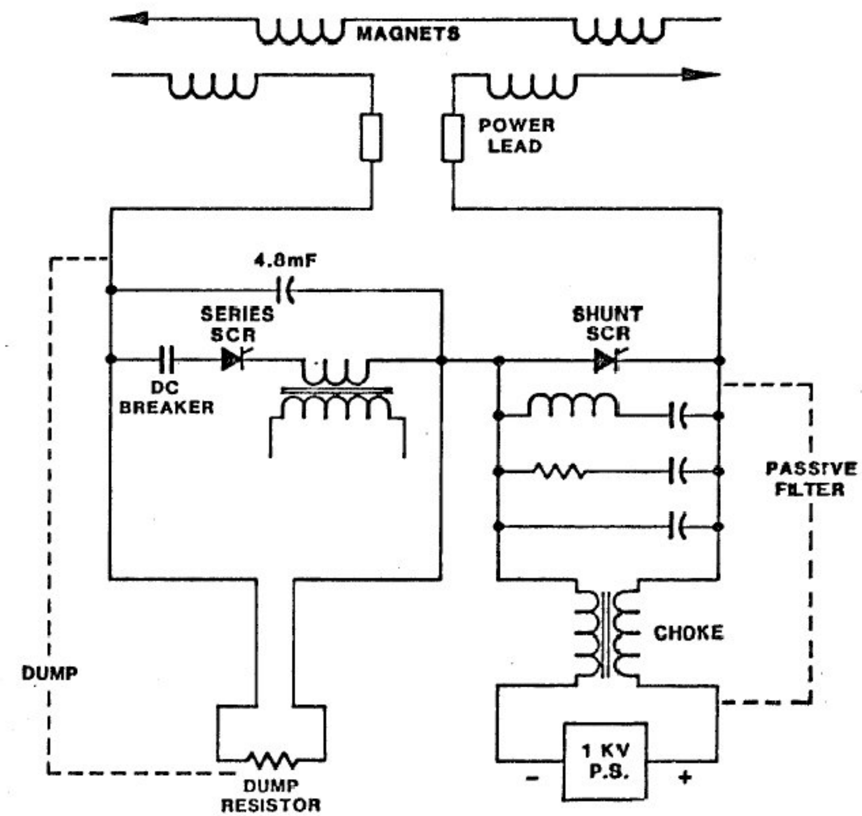
	Dipole
$I_{\text{flat top}}$	4400 A
$U_{\text{flat top}}$	1 kV
$I_{\text{flat bottom}}$	400 A
$U_{\text{flat bottom}}$	42 V
di/dt	67 A/s
Ramping time	60 sec

Tevatron distribution of power supplies

Total of 12 TEV PS's Distributed Around Ring

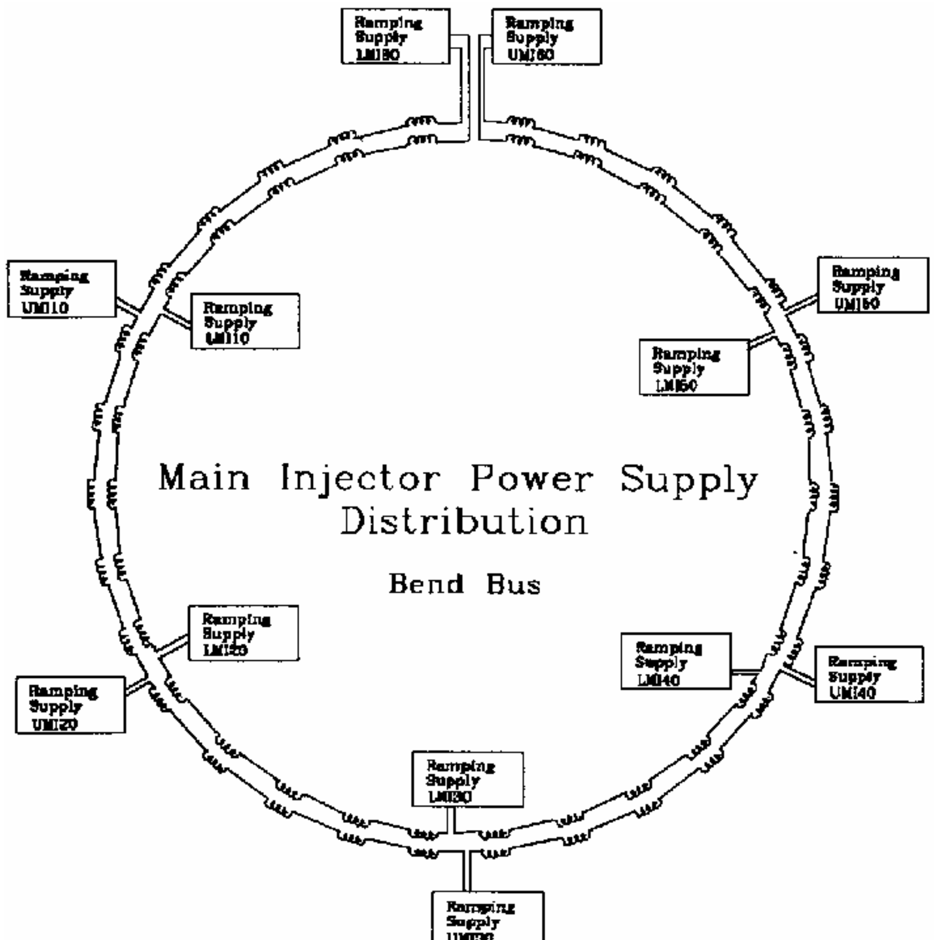


Power supply of Tevatron



TEVATRON POWER SUPPLY SYSTEM
POWER CIRCUIT

Fermilab Main Injector



Fermilab main injector data

Requirement	
Dipole and quadrupole power, peak	120 MVA
Dipole and quadrupole power, average	60 MVA
RF, beamline power supplies, peak	30 MVA
RF, beamline power supplies, average	20 MVA
Backfeed capability, peak	40 MVA
Backfeed capability, average	30 MVA
Accelerator cycling time	1.5 sec

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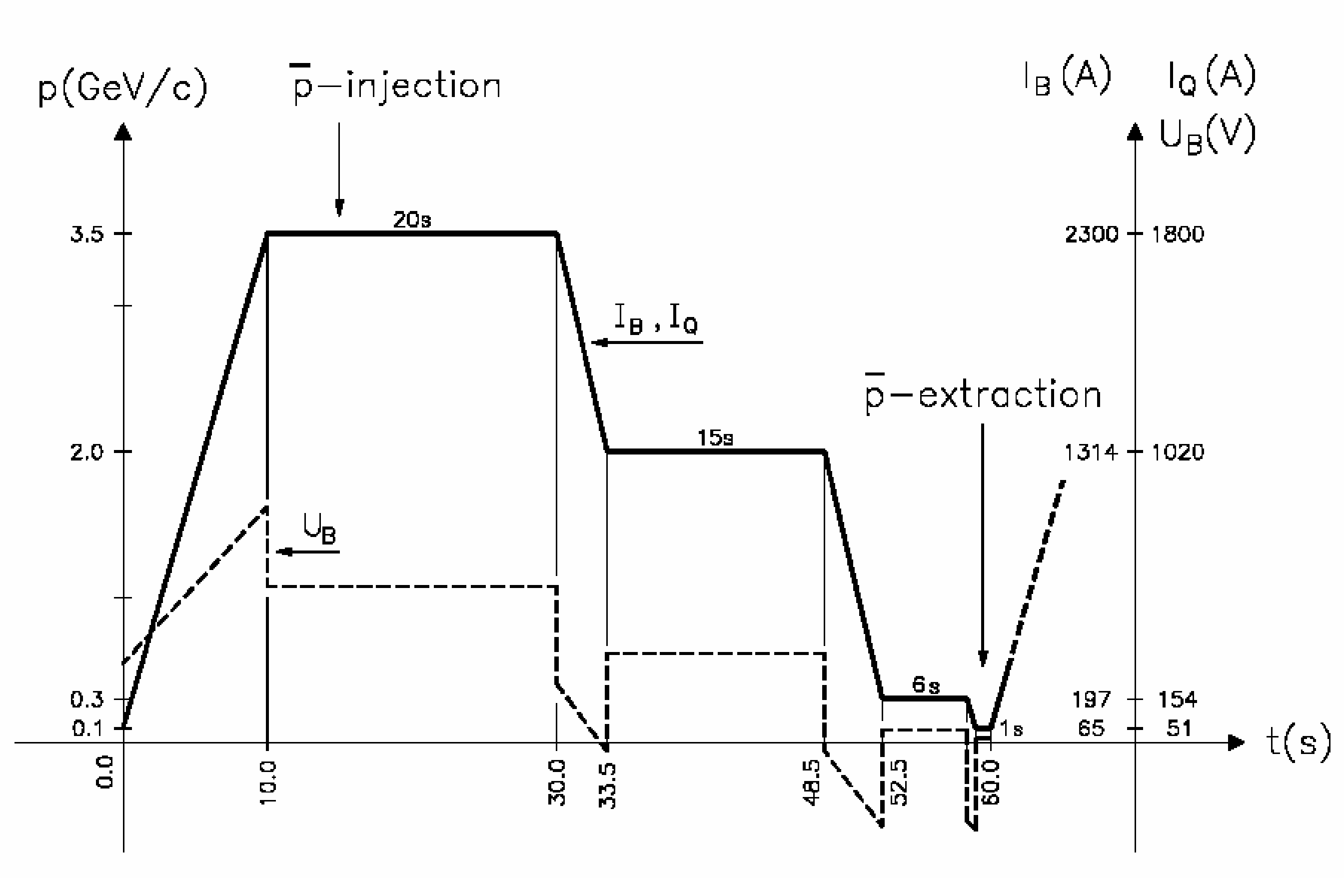
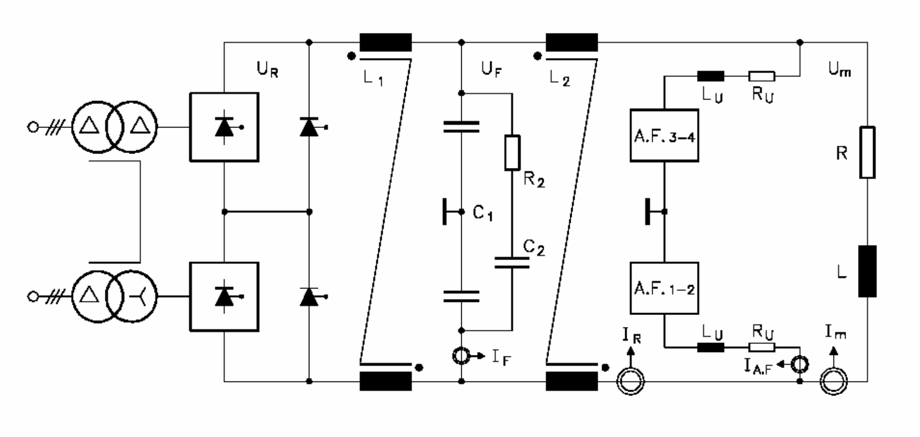
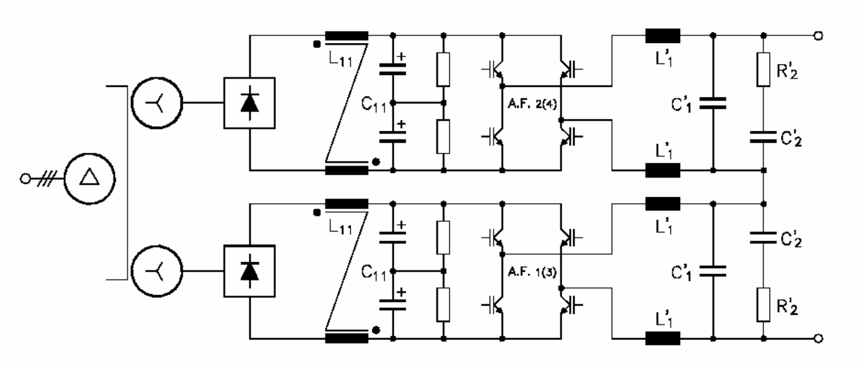
CERN Antiproton Decelerator Cycle

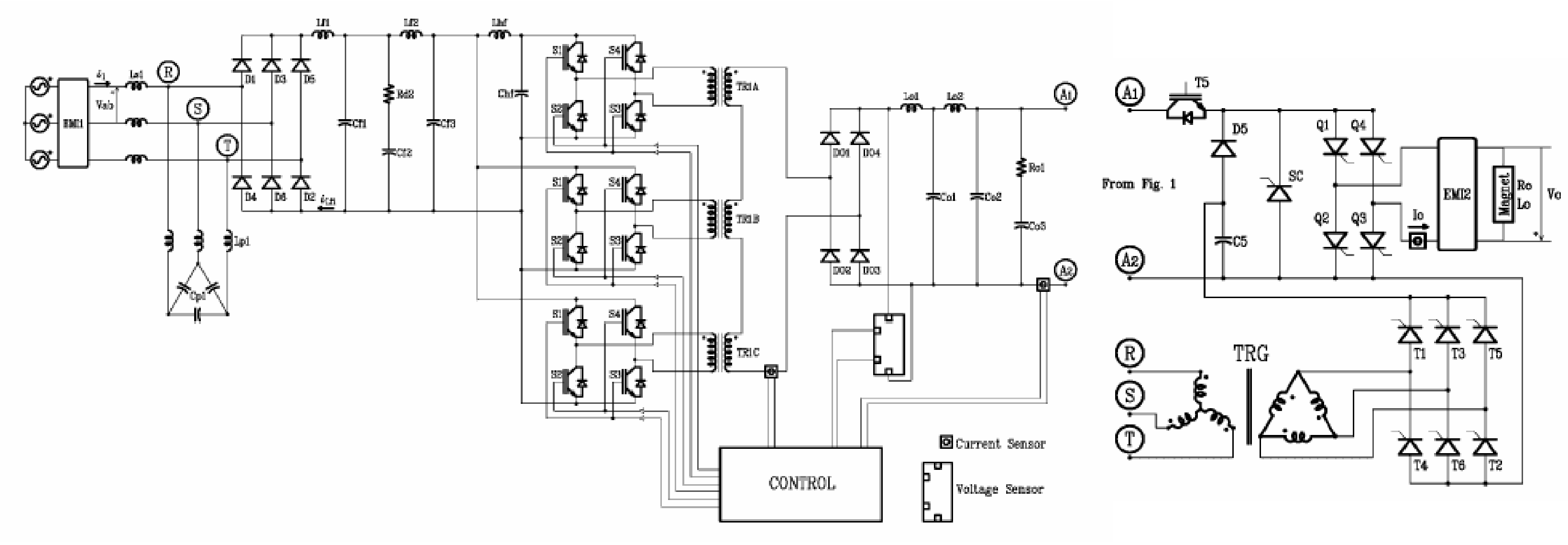


Antiproton decelerator power supply

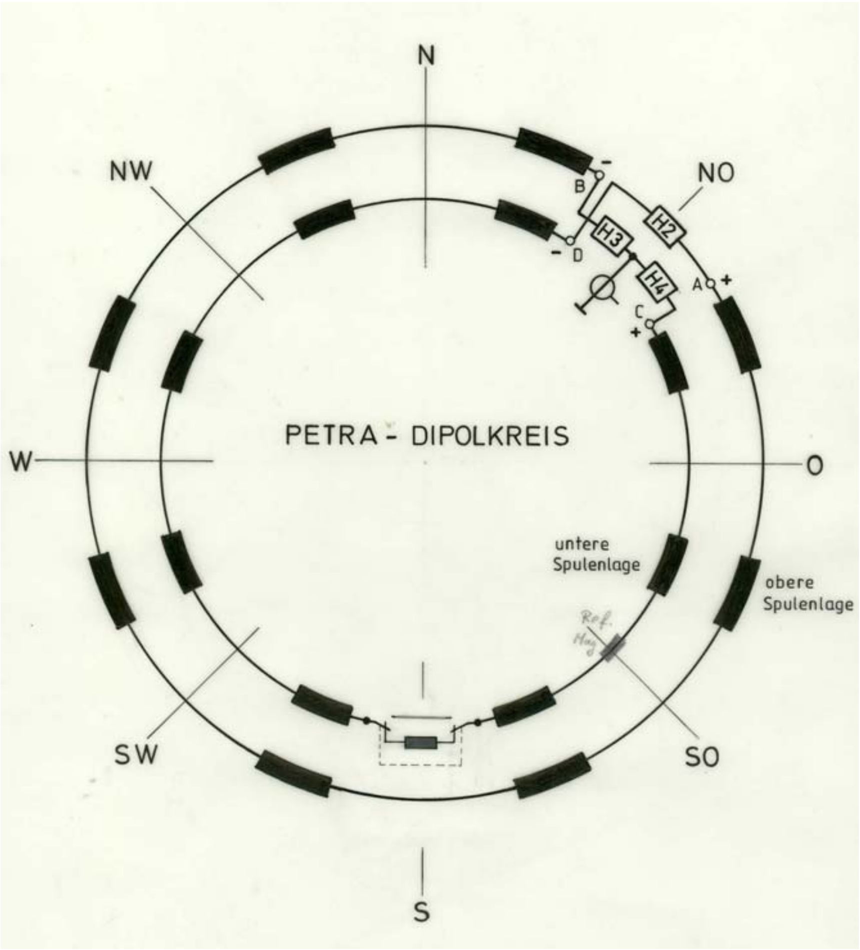




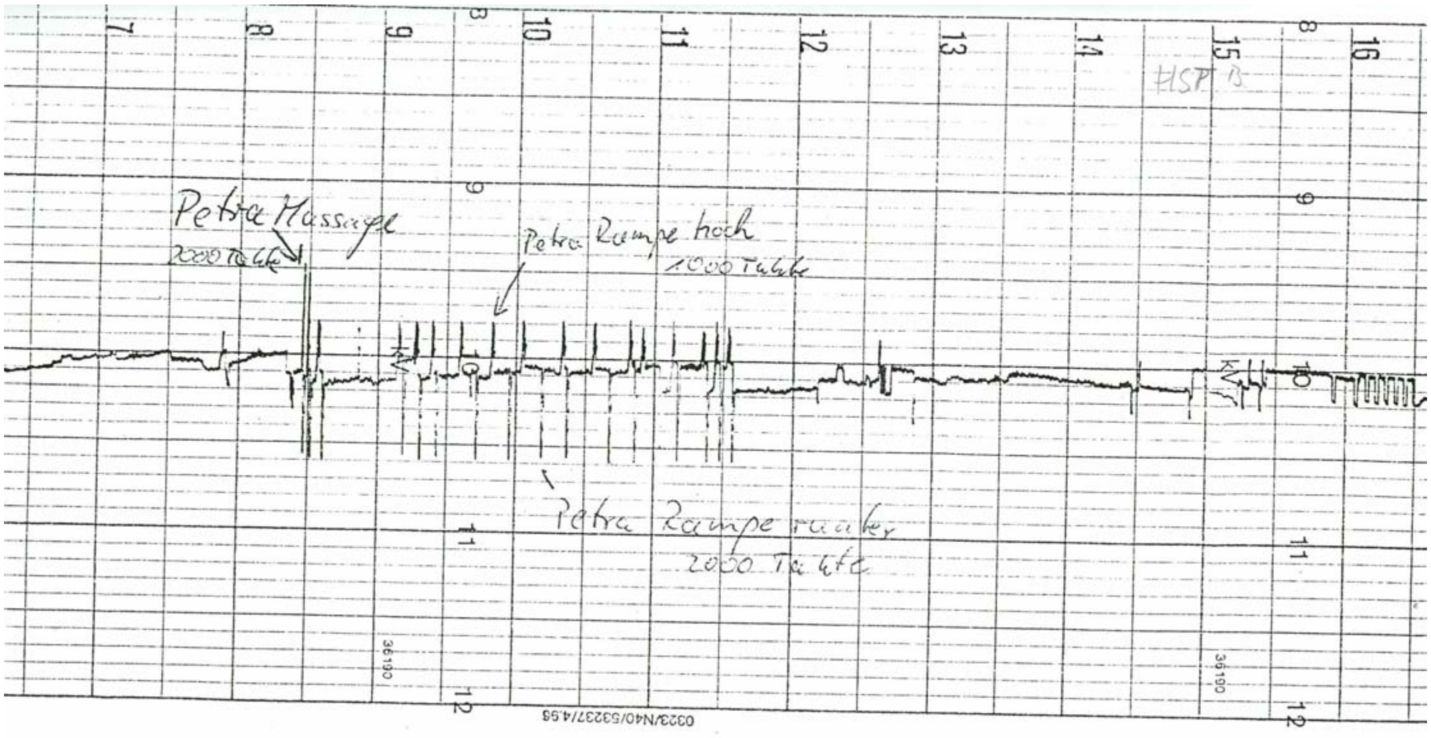
Power supply for the PS-Booster beam transport line with polarity switcher and regenerative circuit



PETRA-Dipole ring



Voltage changes due to the ramping of the PETRA-machine



Slow ramping machines

- HERA
- LEP
- LHC
- Here nearly every lab can be named

- Ramping lasts several minutes or
- Working at steady state
- The variety of power supplies is large and shows in general the state of the art of the power electronics of that time

Different Power Supplies for different machines

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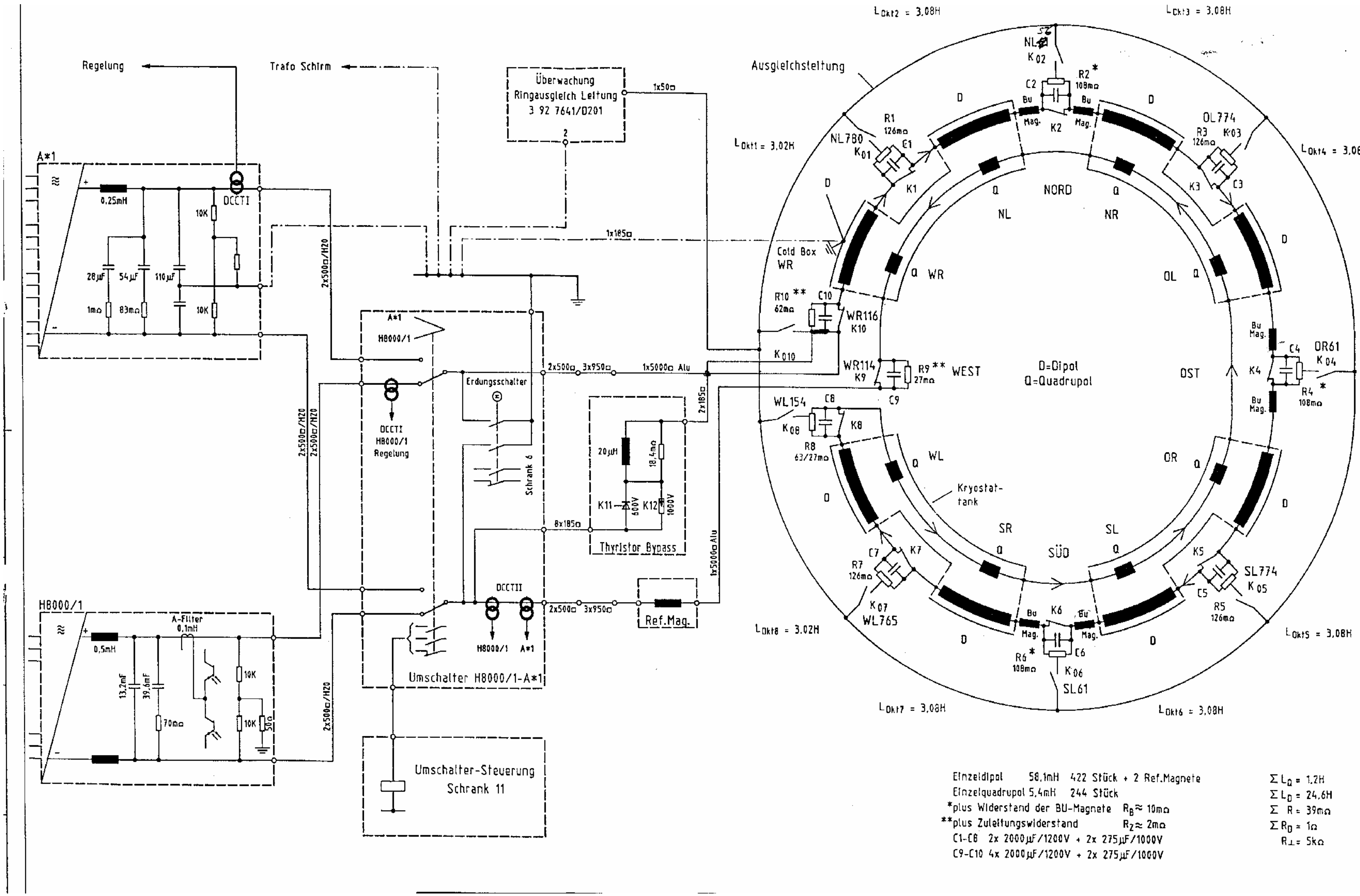
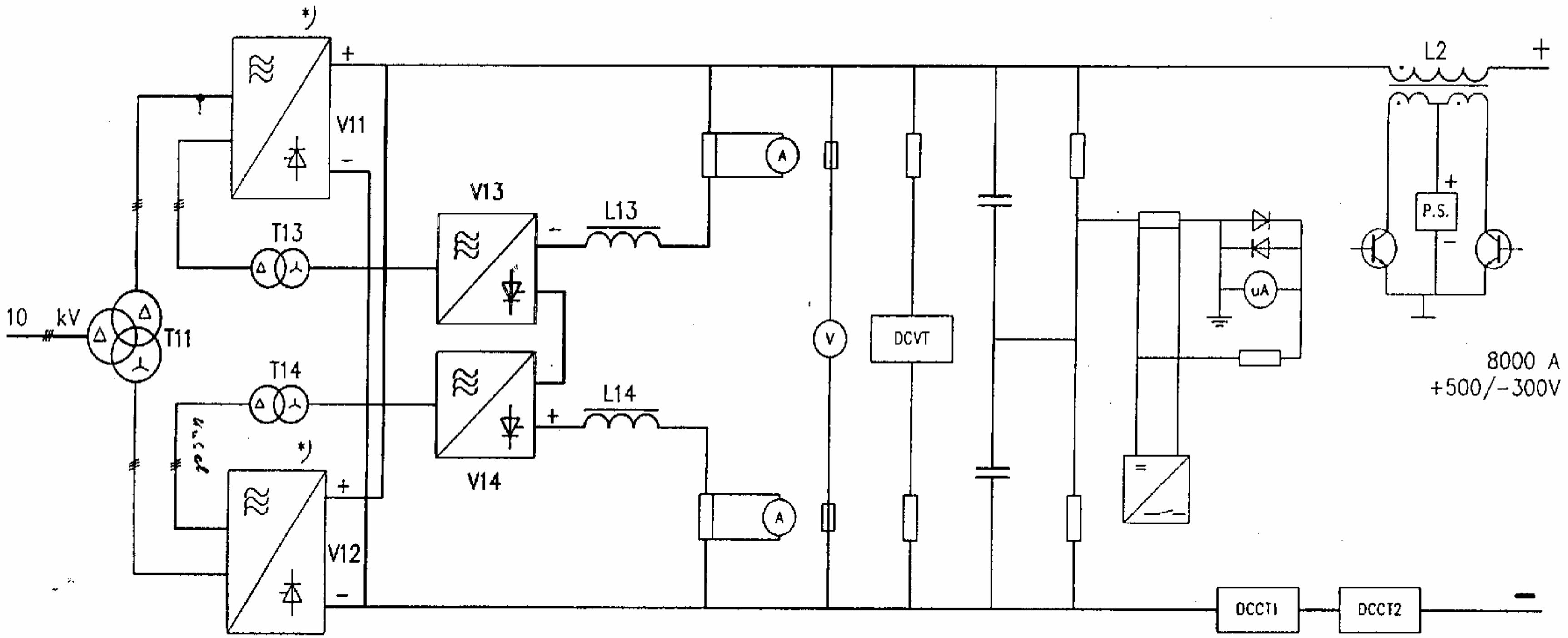


HERA Proton Dipole Power Supply



8000 A, +500V,-300V Optical current 5600A

SCR Power supplies

- Power larger than 50 kW
- Currents larger than 800 A
- Voltages higher than 130 V
- Good prices
- Simple design
- Different Solutions according to the specs
  - LC filter
  - Praeg Filter
  - Active filter

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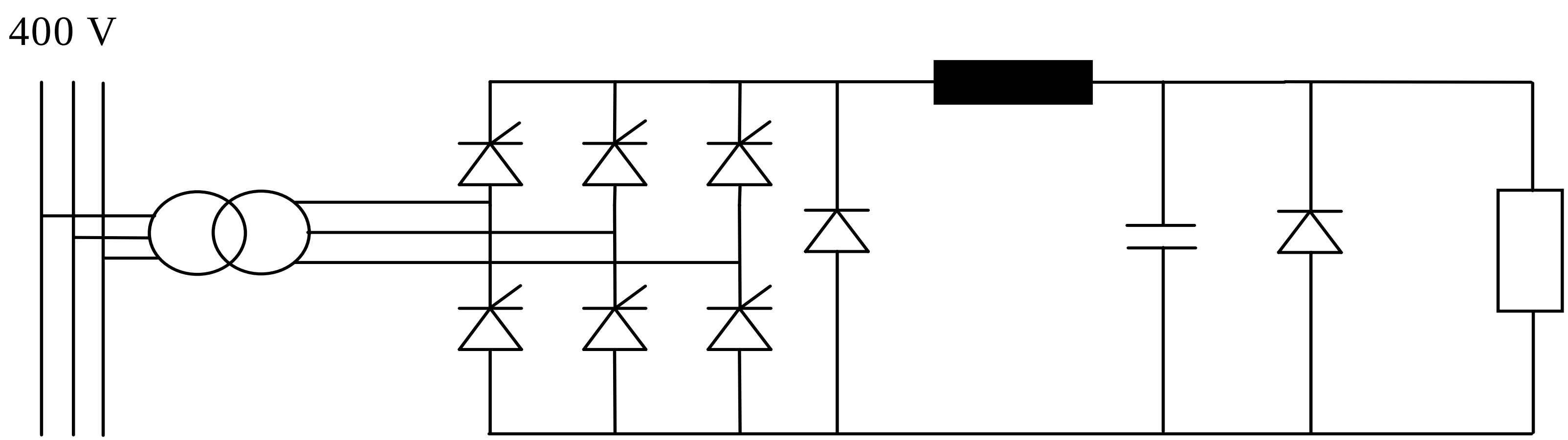
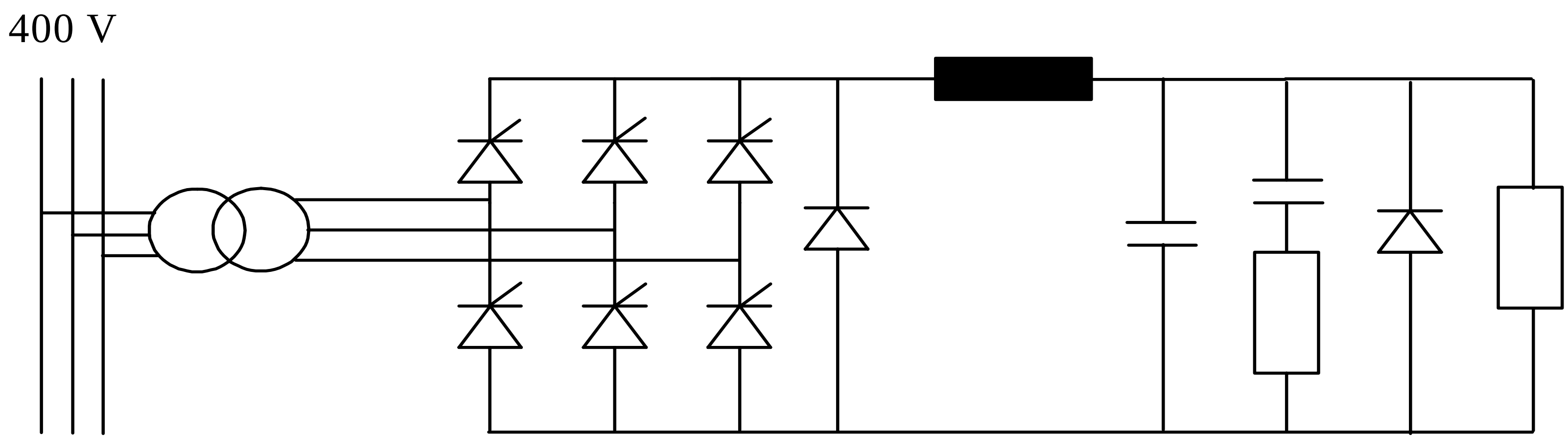
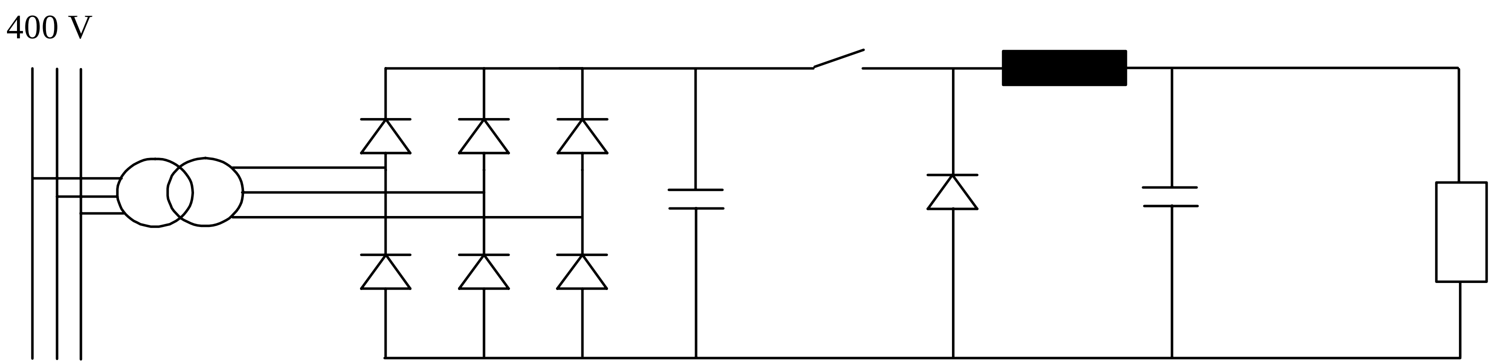
SCR supply with LC filter



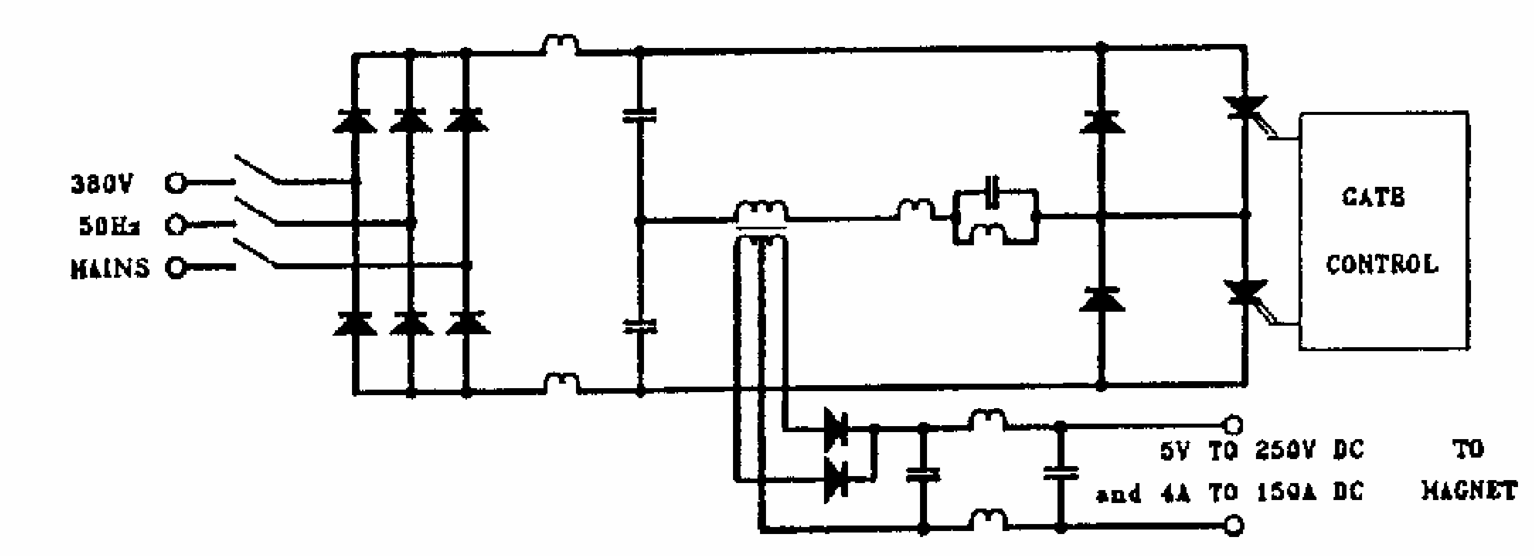
SCR Power supply with Praeg filter



HERA Buck converter



Schematic of the LEP double resonant power supply



125 V, 300 A **or** 188 V, 200 A **or** 250 A, 150 V

LHC 600A/10V, 40V Power supply

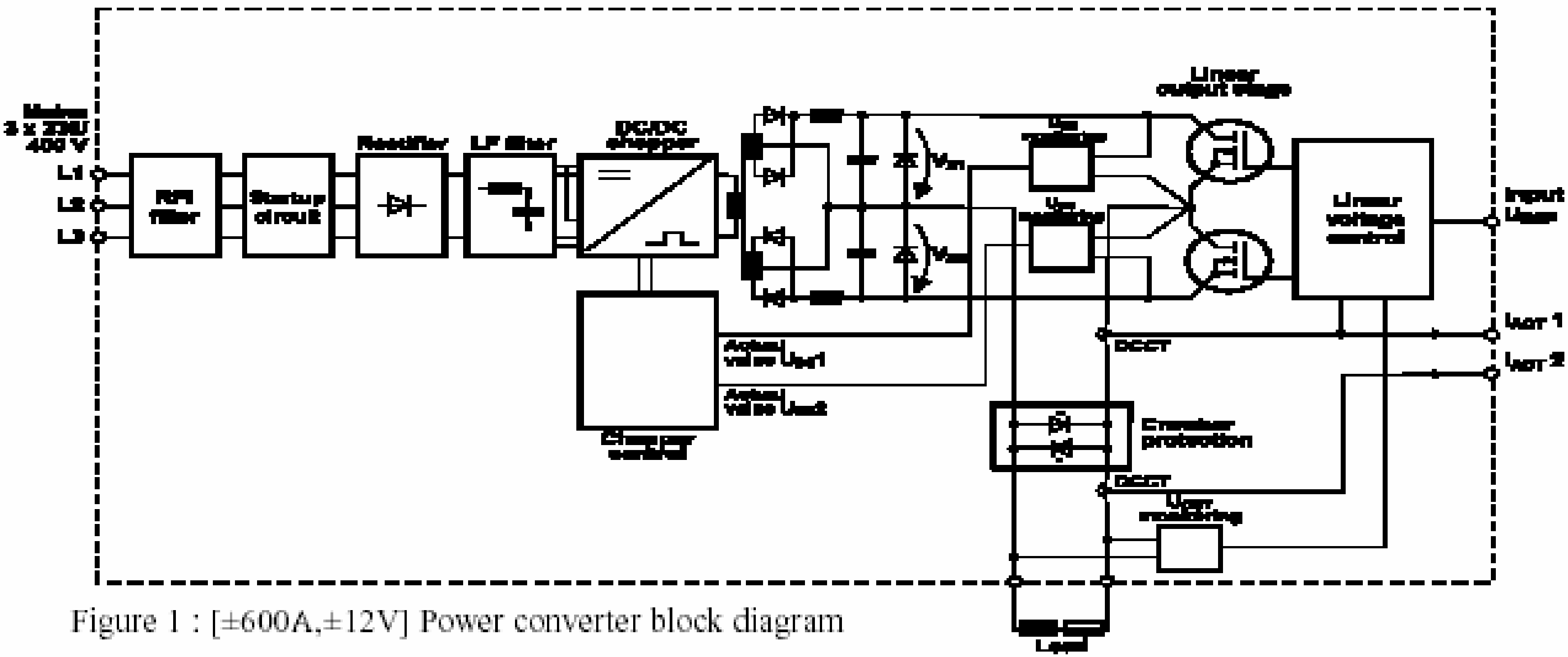
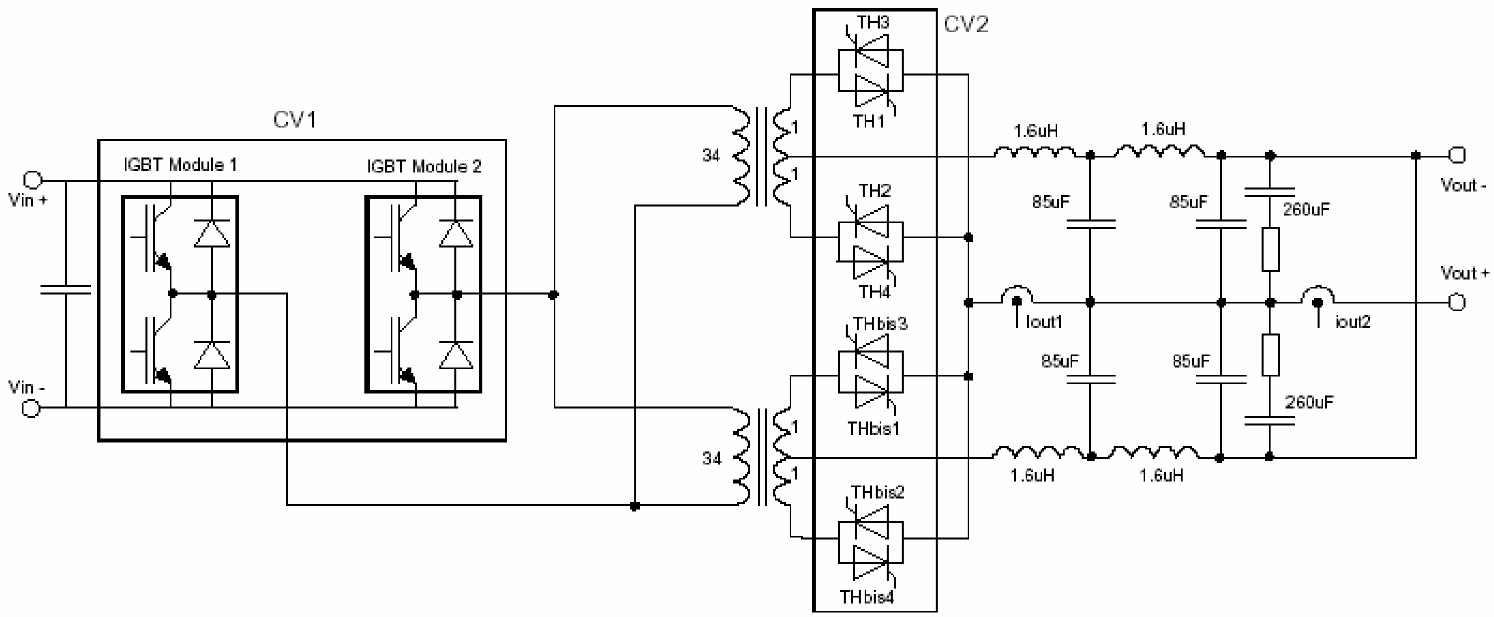
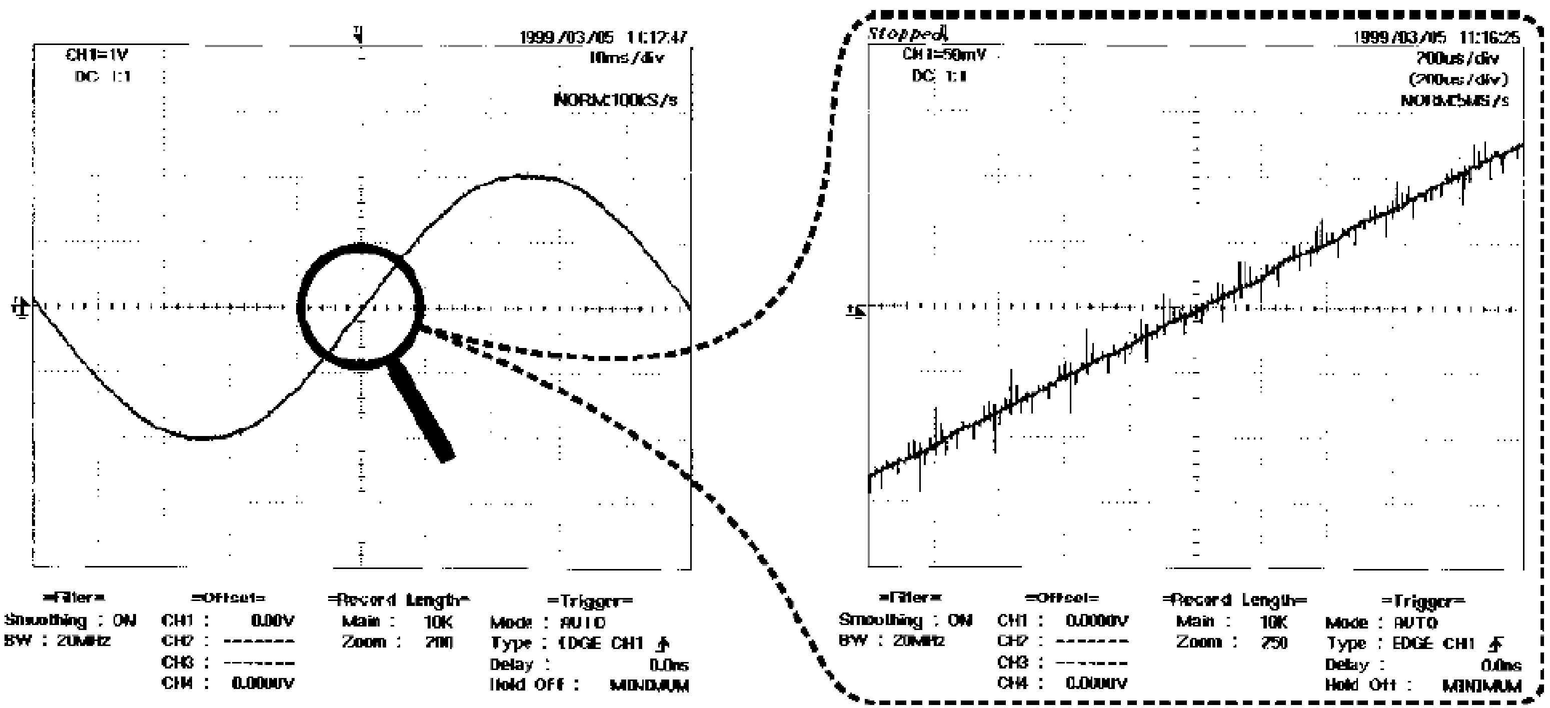


Figure 1 : [±600A,±12V] Power converter block diagram

LHC 600A/10V, 40V Power supply



LHC 600A/10V, 40V Power supply



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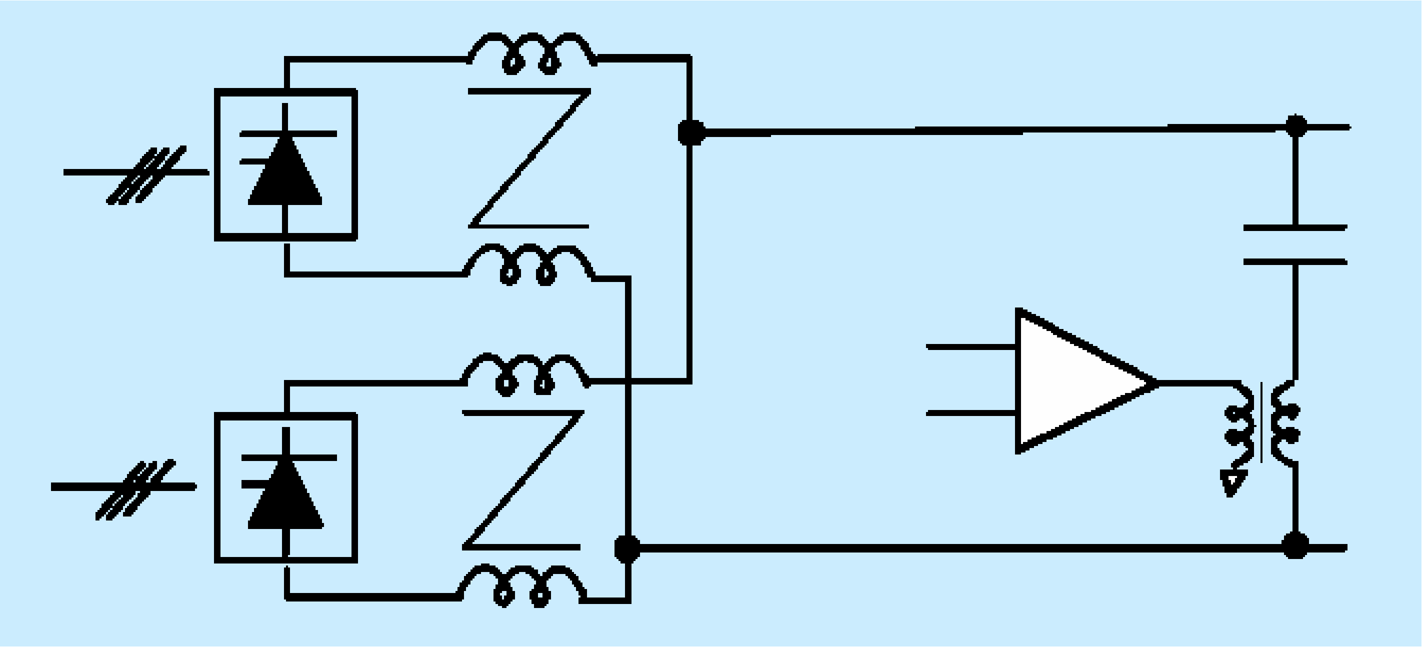
SCR unit for LHC transport line with active filter

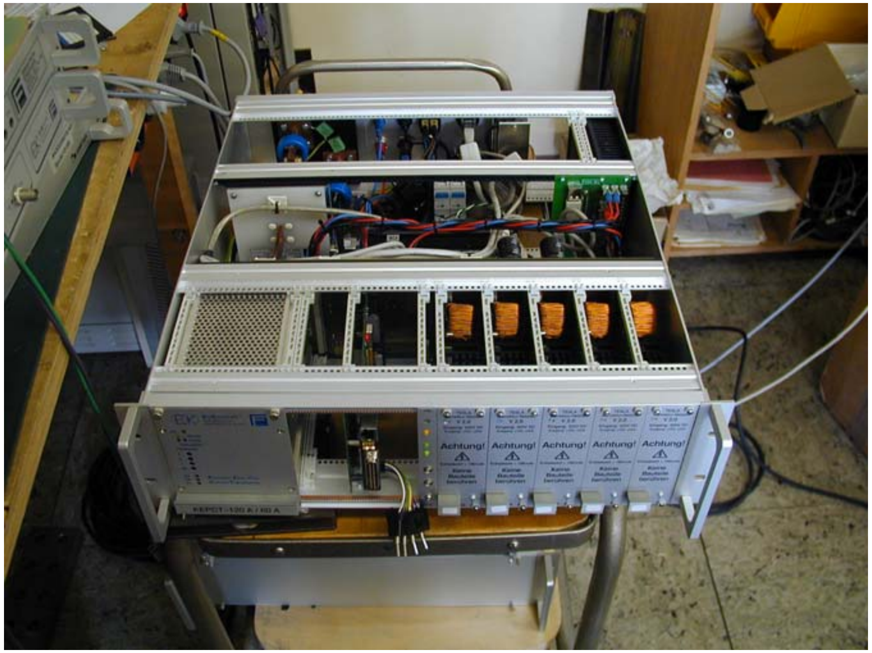


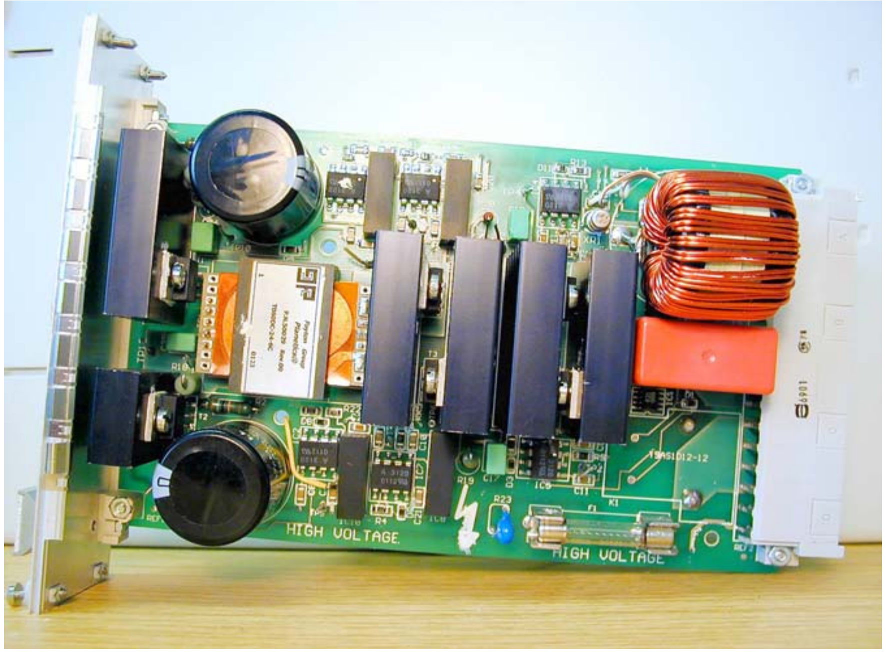
Pulsed machines

- Linear Collider, sometimes, somewhere
- XFEL, Hamburg
- VUV-FEL, Hamburg

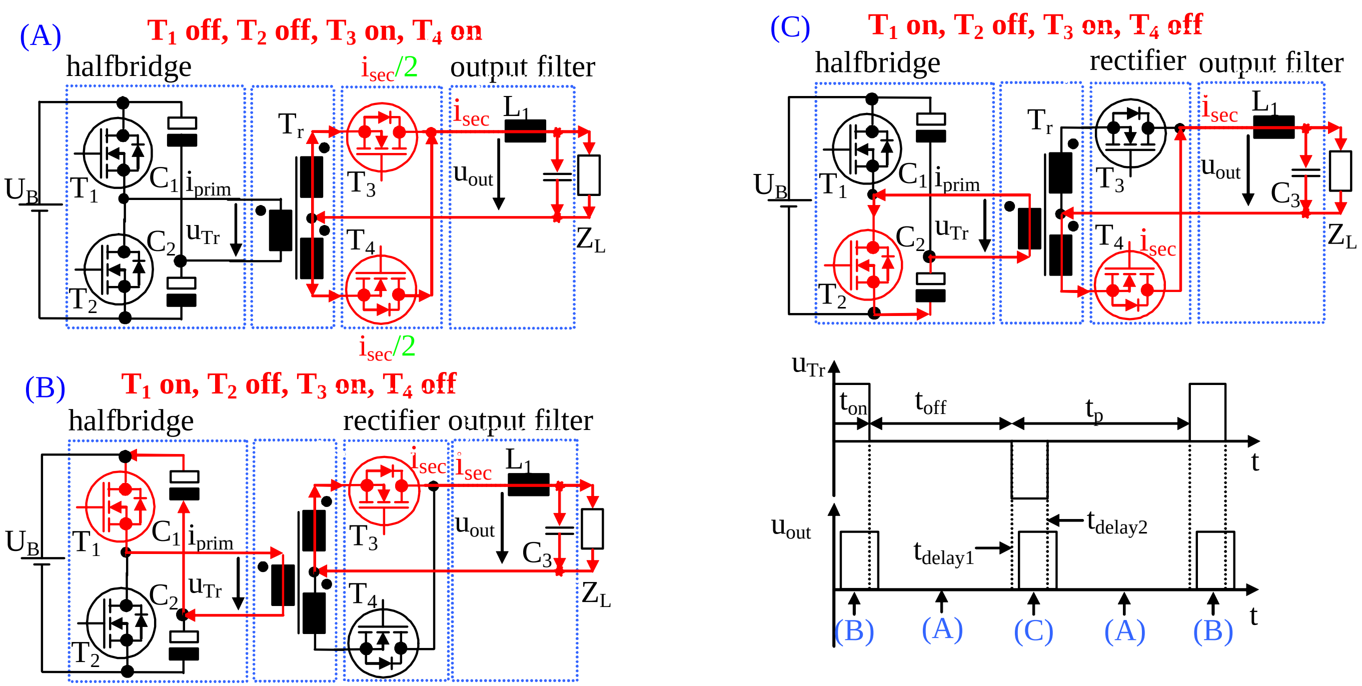
- Machines are working with short pulses between a few µsec up to ms
- Repetition rates between 1 and 50 Hz
- High demands on power supplies
- Suppress the repetition rate toward the grid

New XFEL power supply for sc QP +/- 100 A/10V

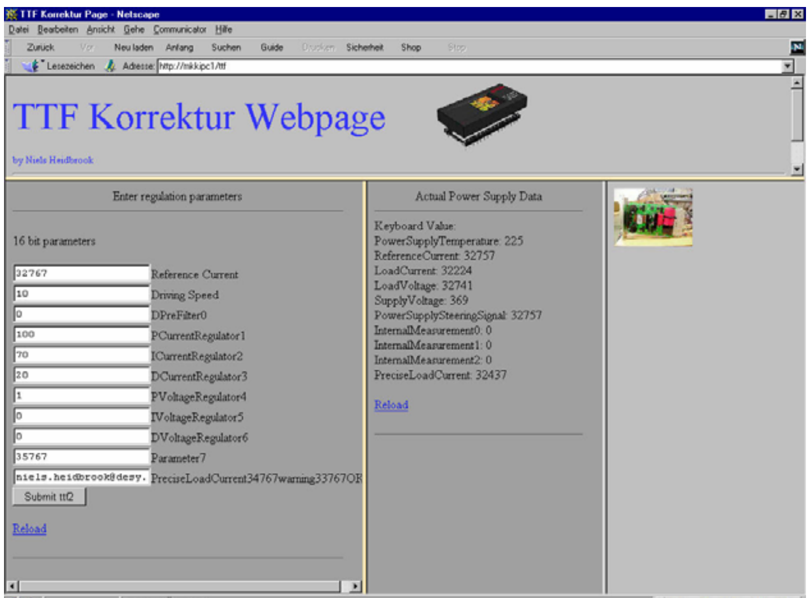


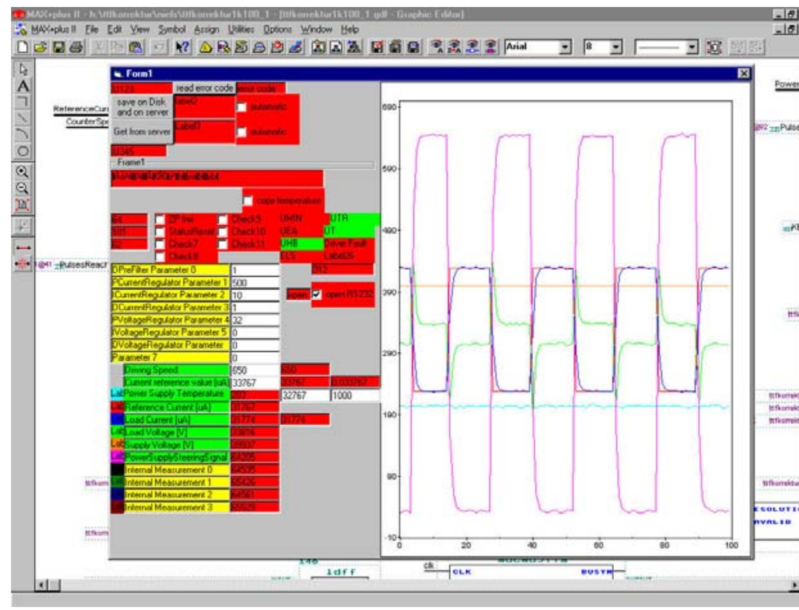


XFEL Power supply

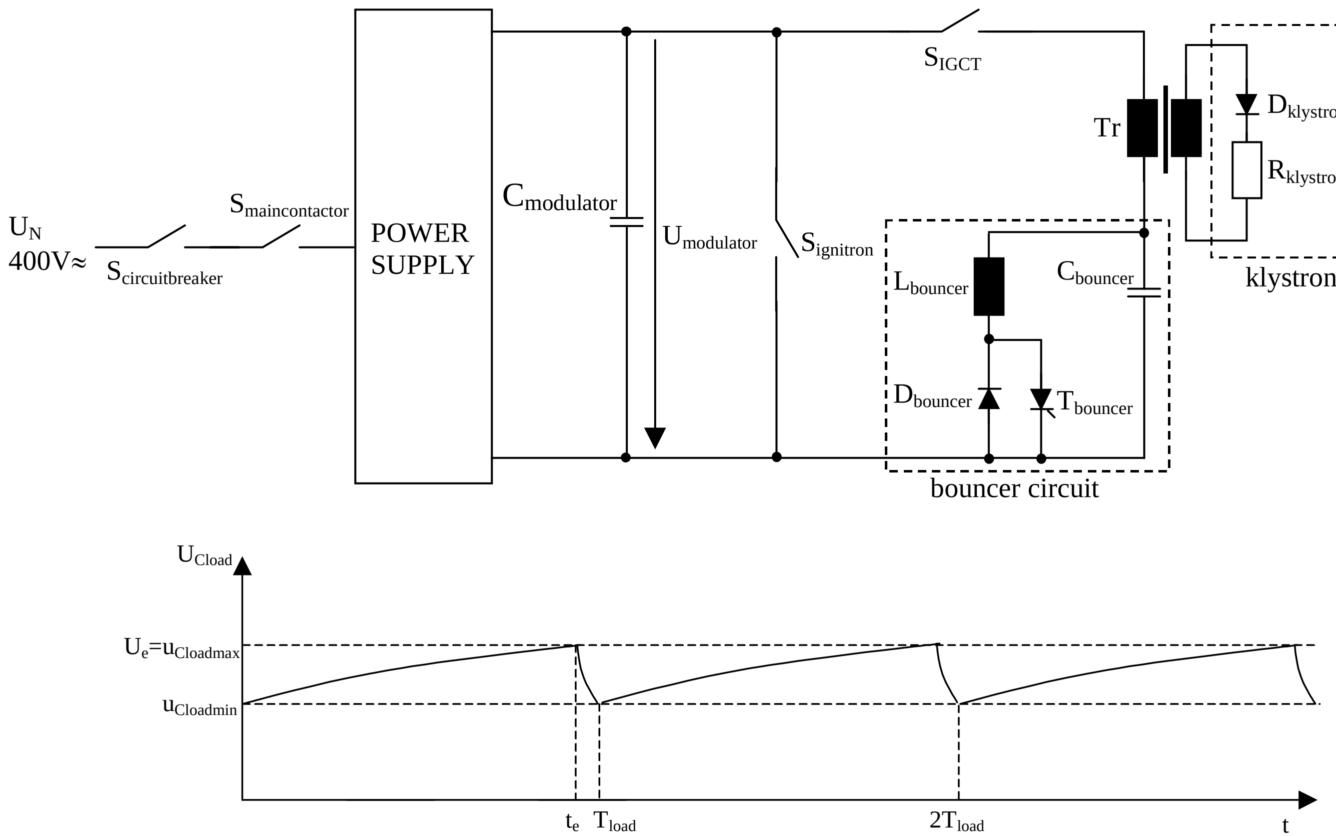


Web Access to the power supply

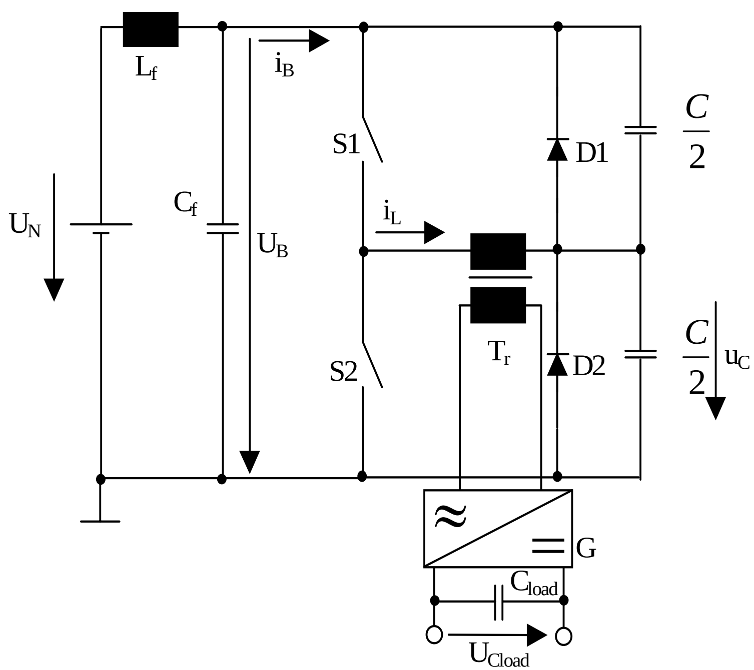




Voltage at XFEL Modulator

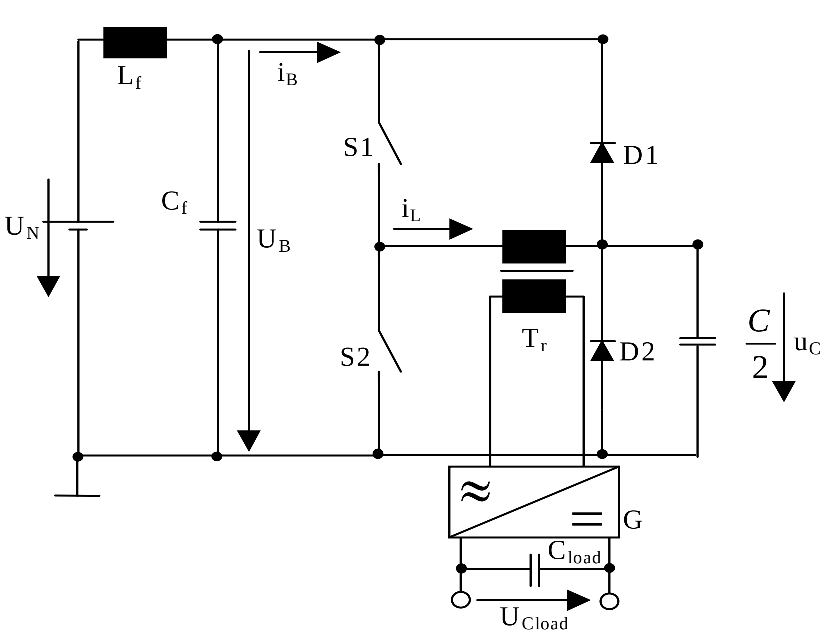


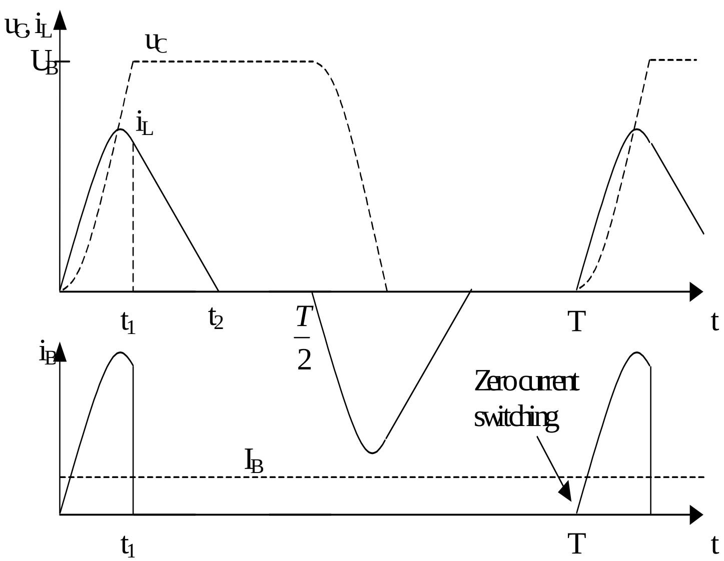
Switched mode power supply for constant power



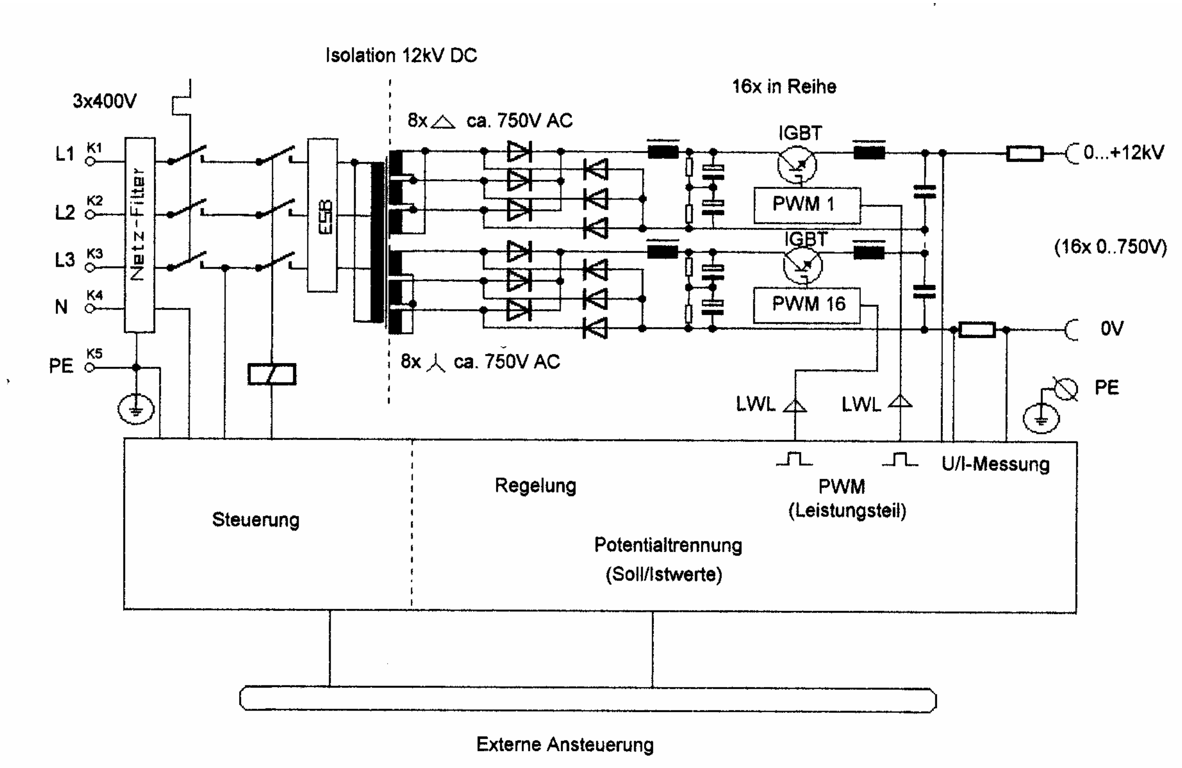
G	Rectifier
i_B	supply current
i_L	primary current of the transformer
u_C	voltage of the resonance capacitor
U_{Cload}	output voltage to the switch of the klystron
i_{Bt1}	current i_B at the time t1
L	primary stray inductivity of the transformer
f	resonance frequency of the resonant circuit of L and C
n	gear ratio of the transformer and rectifier
T	period time of the switching frequency of S1 and S2
C	resonance capacitor
U_B	supply voltage
U_N	line voltage
C_f	filter capacitor
L_f	filter inductance

Derivation of the equivalent circuit to the switch mode power supply





Series connection of buck converters



Conclusion

- There are a lot of very interesting power supplies in the machines
- This was only a very short overview of what is installed into machines over the world
- It shall give an idea what kind and where solutions and help are to find when someone encounters a new problem
- A very good source of information is:
    - Joint Accelerator Conferences Website
    - http://accelconf.web.cern.ch/AccelConf/

Thanks for your attention