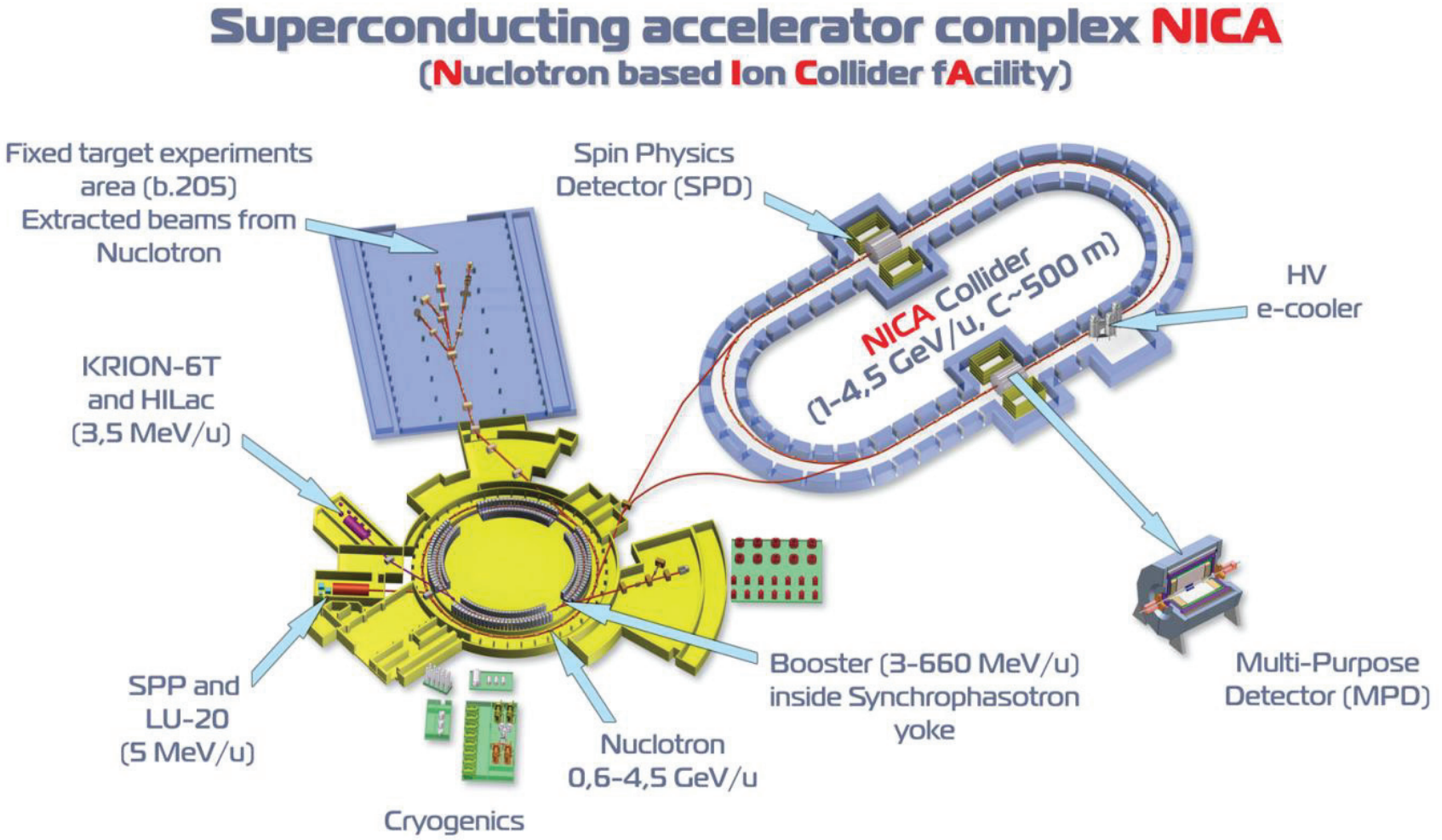
RuPAC-21

Features of power supply systems for superconducting structural magnets of NICA accelerators.

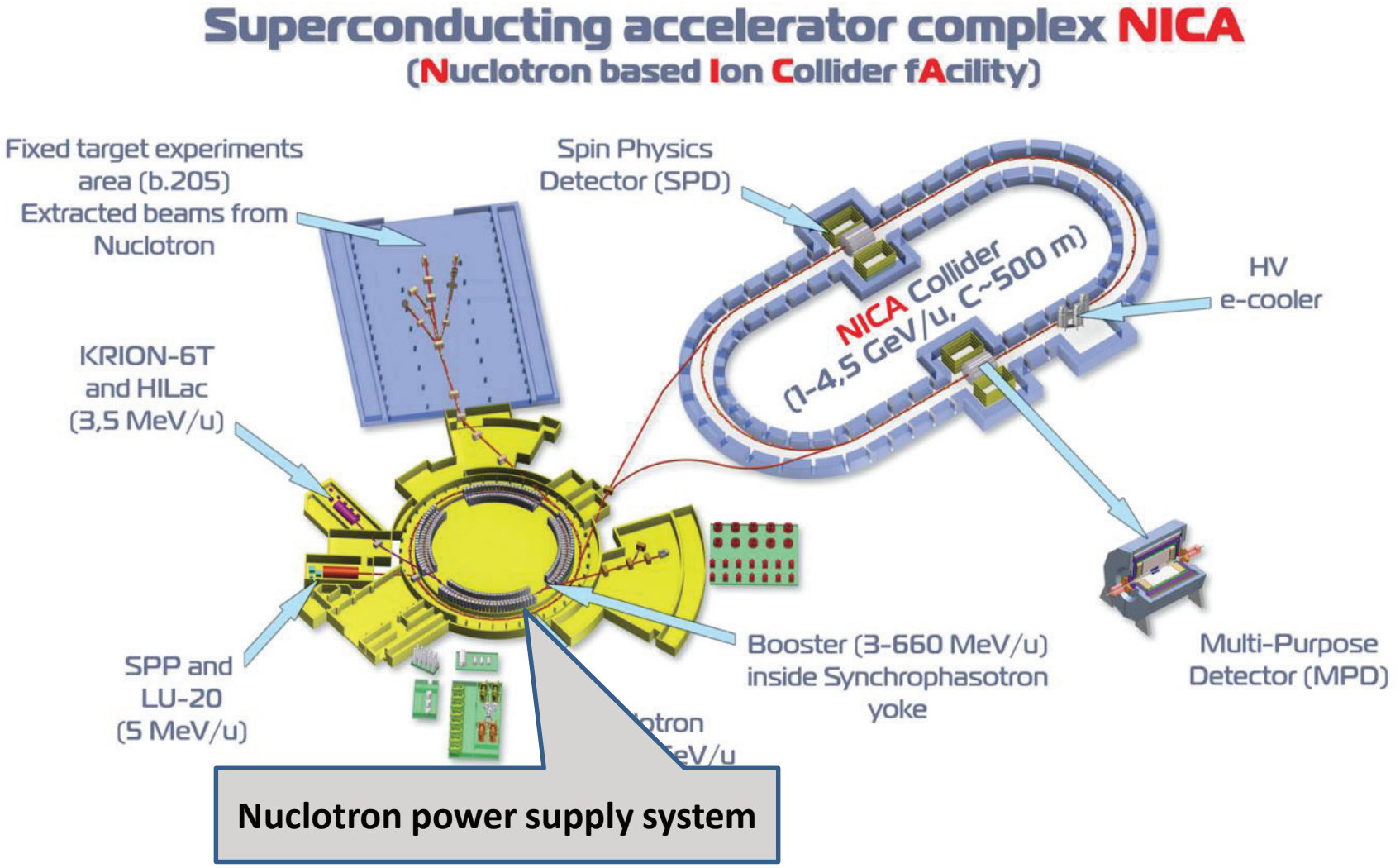
V.Karpinskii and all
AD LHEP

29 september 2021, Alushta, Crimea

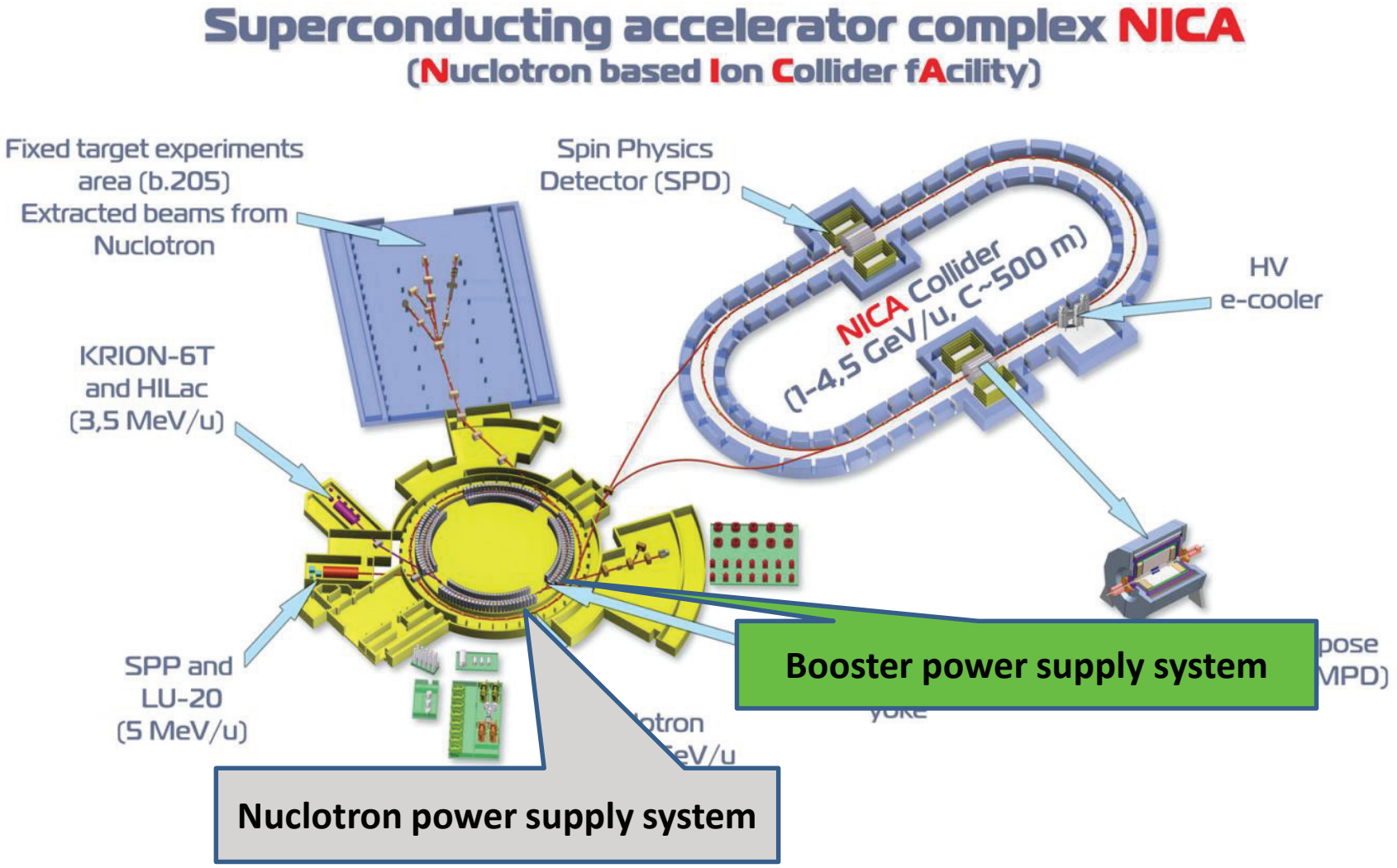
Basic NICA installations



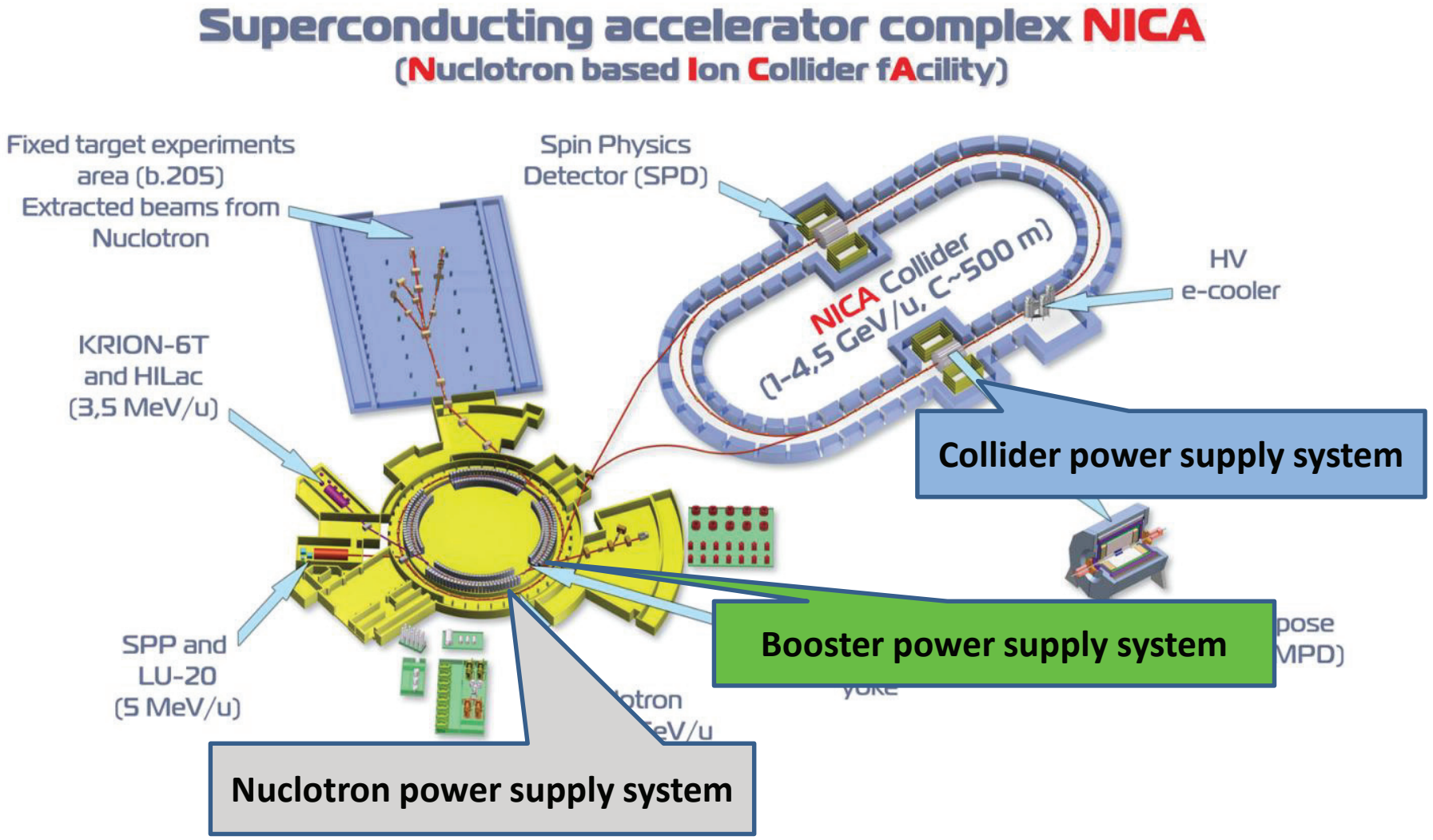
Basic NICA installations



Basic NICA installations



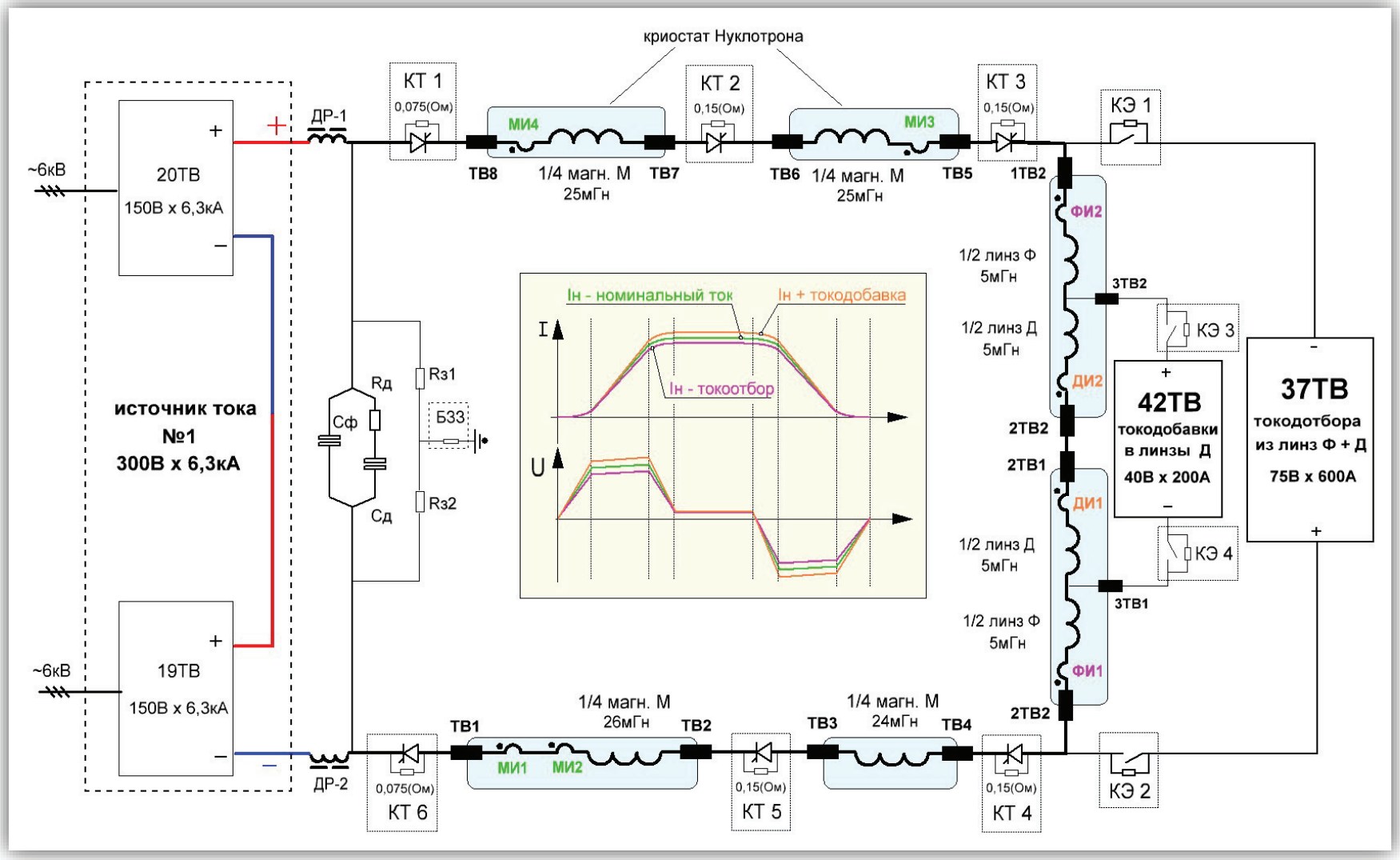
Basic NICA installations



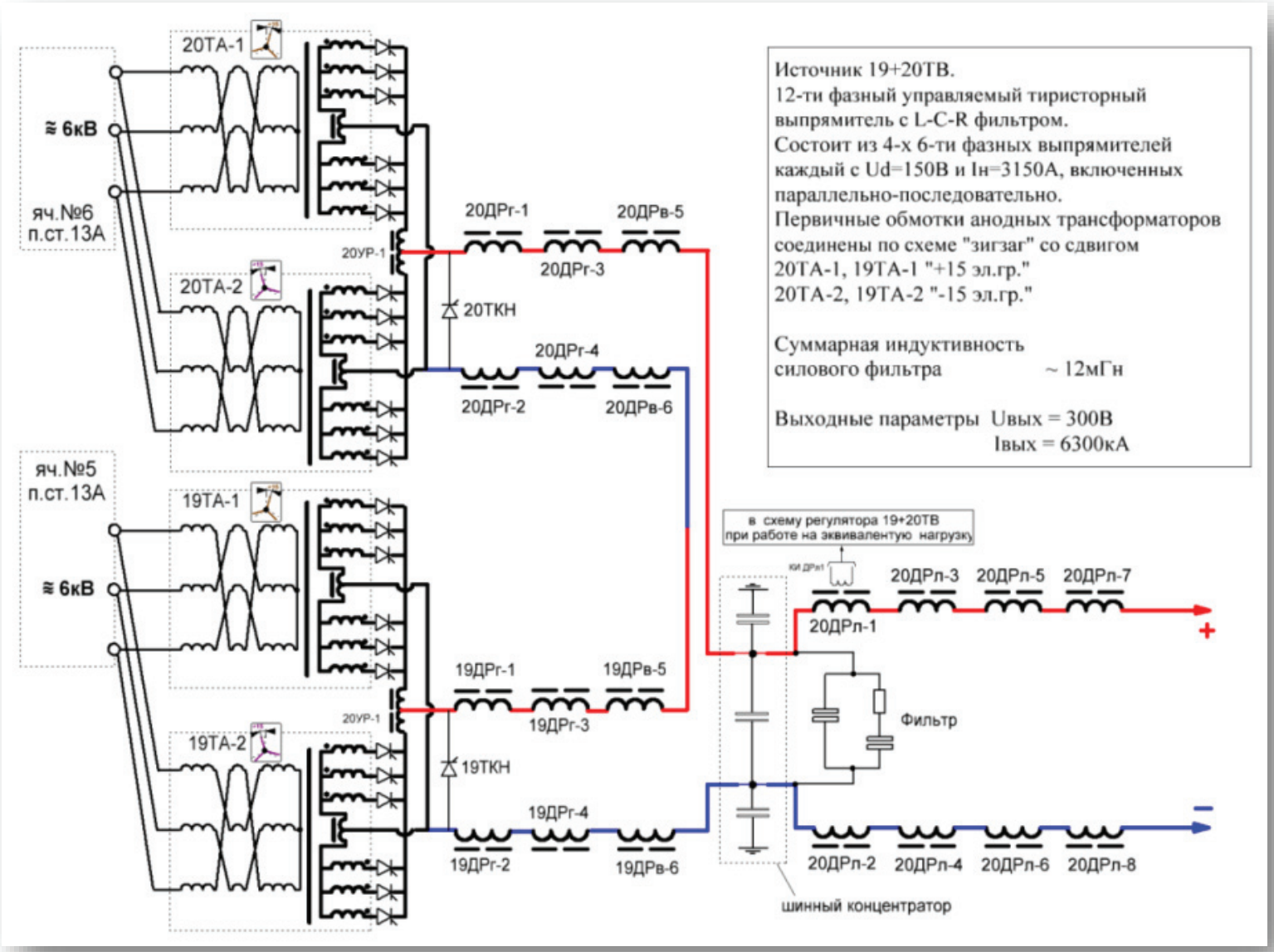
Specifics of power supply systems of superconducting structural magnets of synchrotrons and Collider

- Modern accelerator complexes require precision power supply systems of MW-power, the stability of load currents should be $\Delta I/I \sim$ 1E-4…1E-5
- Superconducting magnets (pure inductive load) at high-speed current requires operation in the maximum dynamic range of voltage
- Providing a given ratio of fields in all families of magnetic elements
- The power supply system should include a subsystem of emergency evacuation of energy from the SC-magnets.

Schematic diagram of the Nuclotron power supply system



Block diagram of the source 19TV 20TV

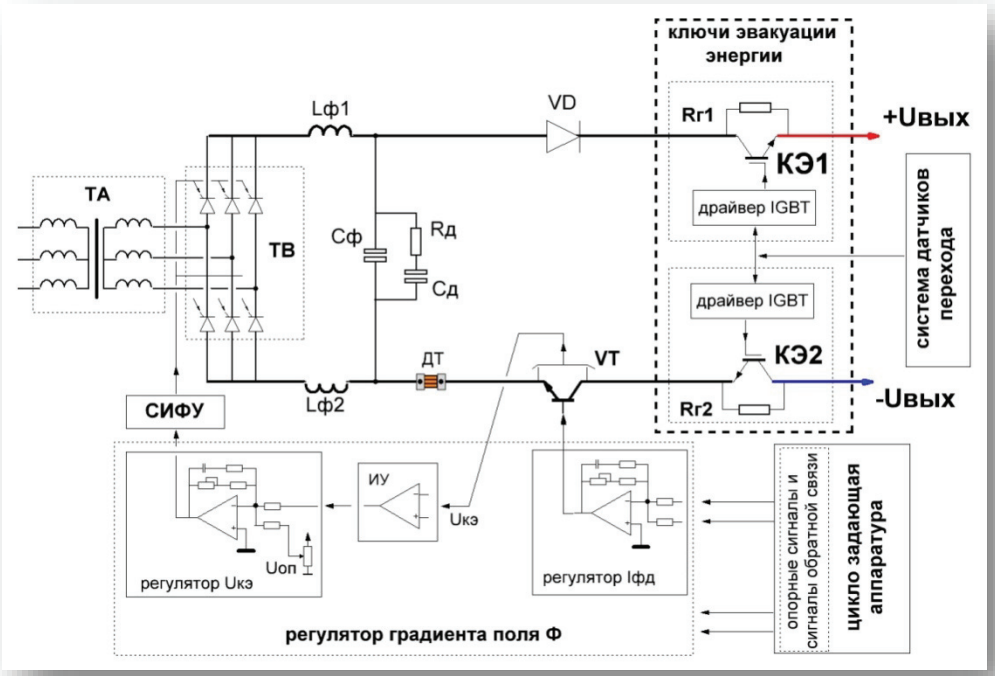


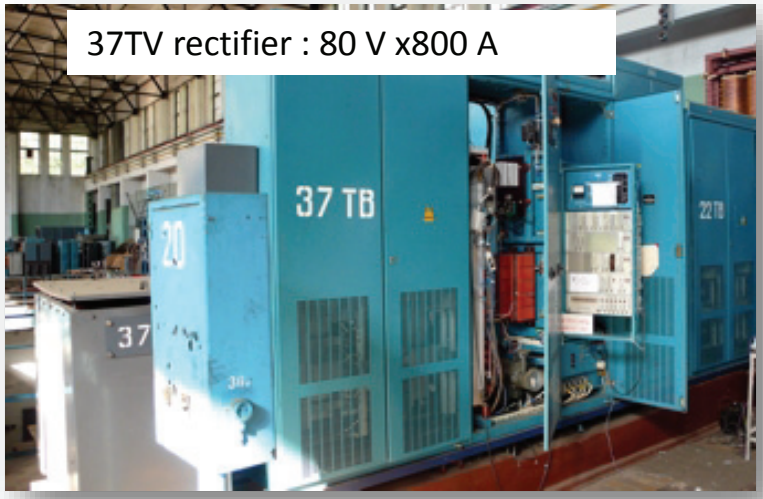
Nuclotron power supply System

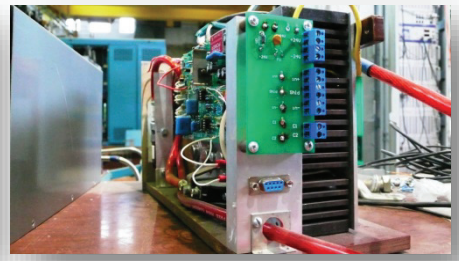
Block diagram of the source 19TV 20TV

Nuclotron power supply System

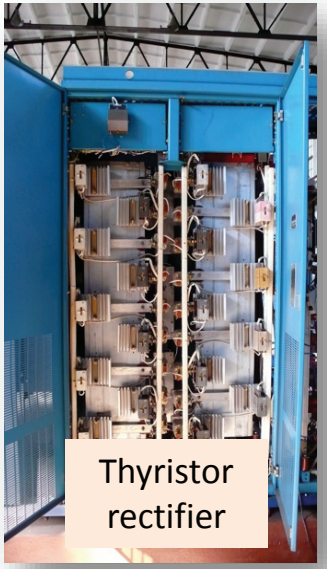
Block diagram of the source 37TV

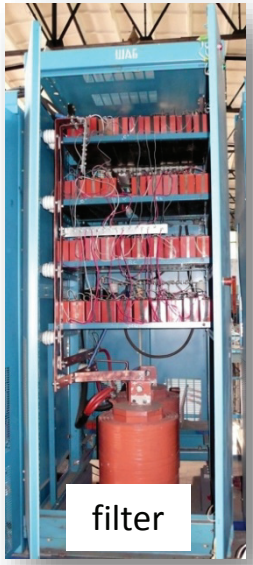






linear regulator RT 01: 10V x 50A, total 12 units



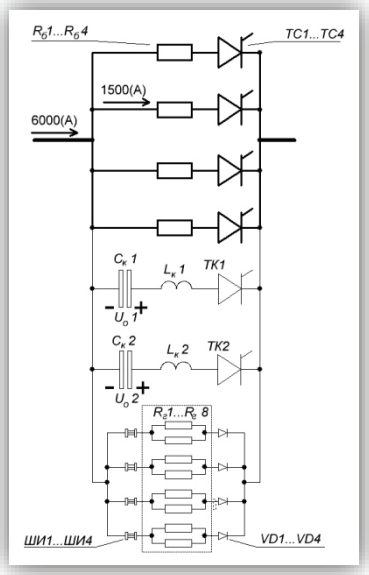


System energy evacuation from the SC-magnets

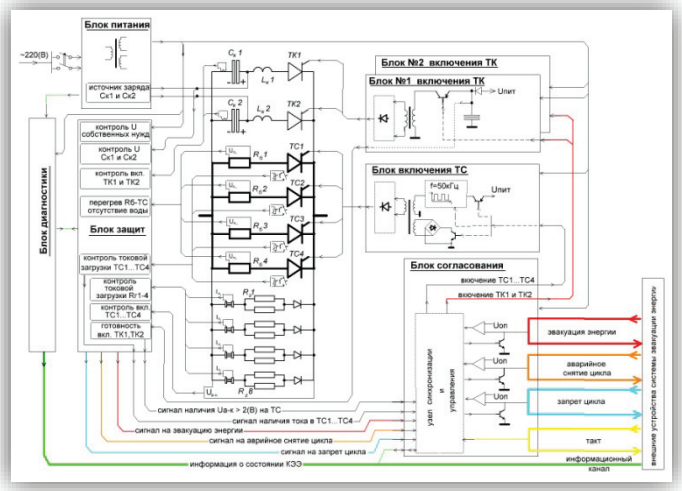
Requirements for the system of energy evacuation from the SC-magnets of the Nuclotron

1) energy output constant - **160ms,**
2) the potential of the magnetic elements relative to the "earth" - **not more than 500V,**
3) **reliability.**

Power circuit



Schematic diagram

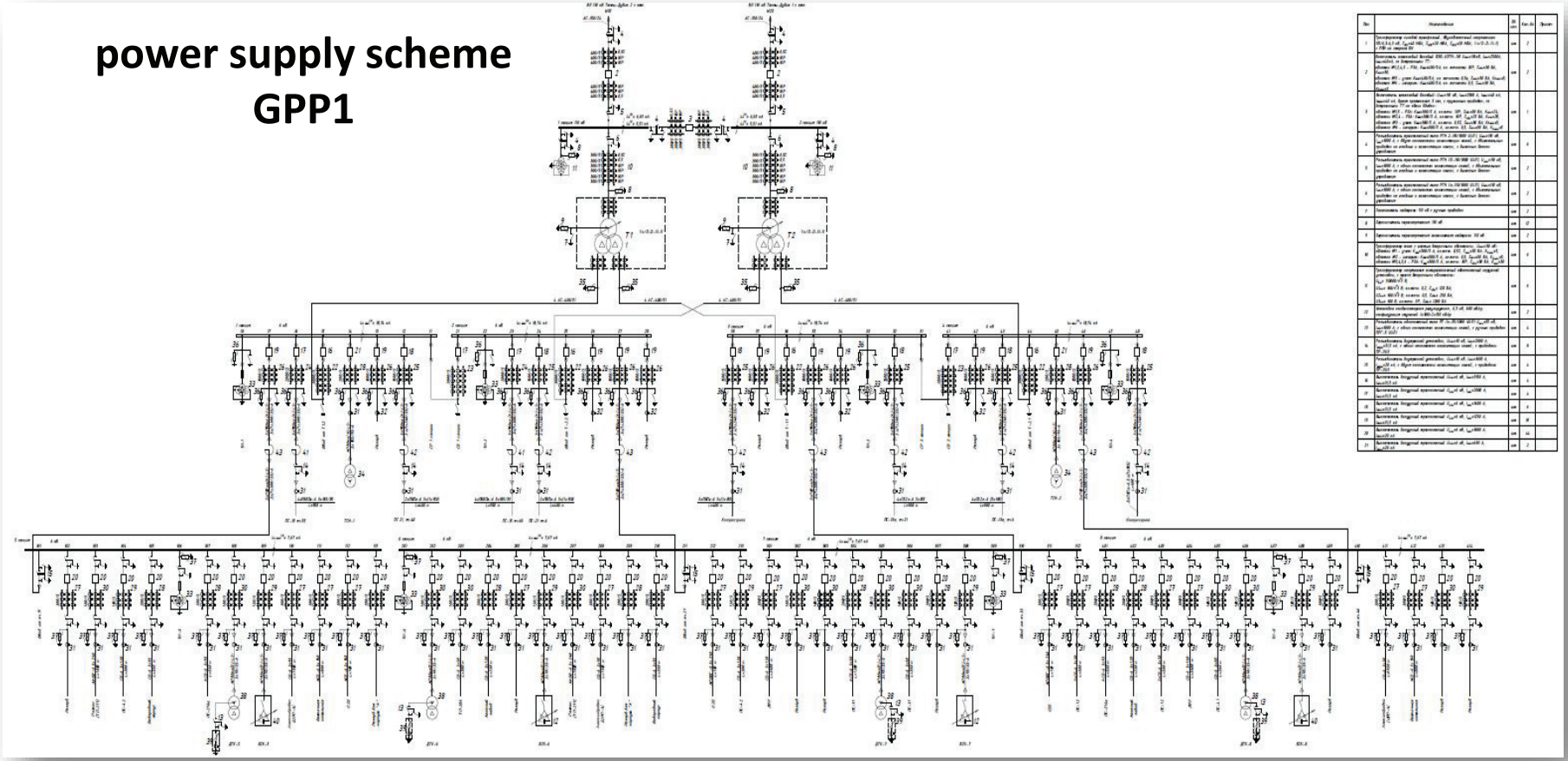


Common view

Nuclotron power supply System

Power consumption of the network is 6 kV

power supply scheme
GPP1



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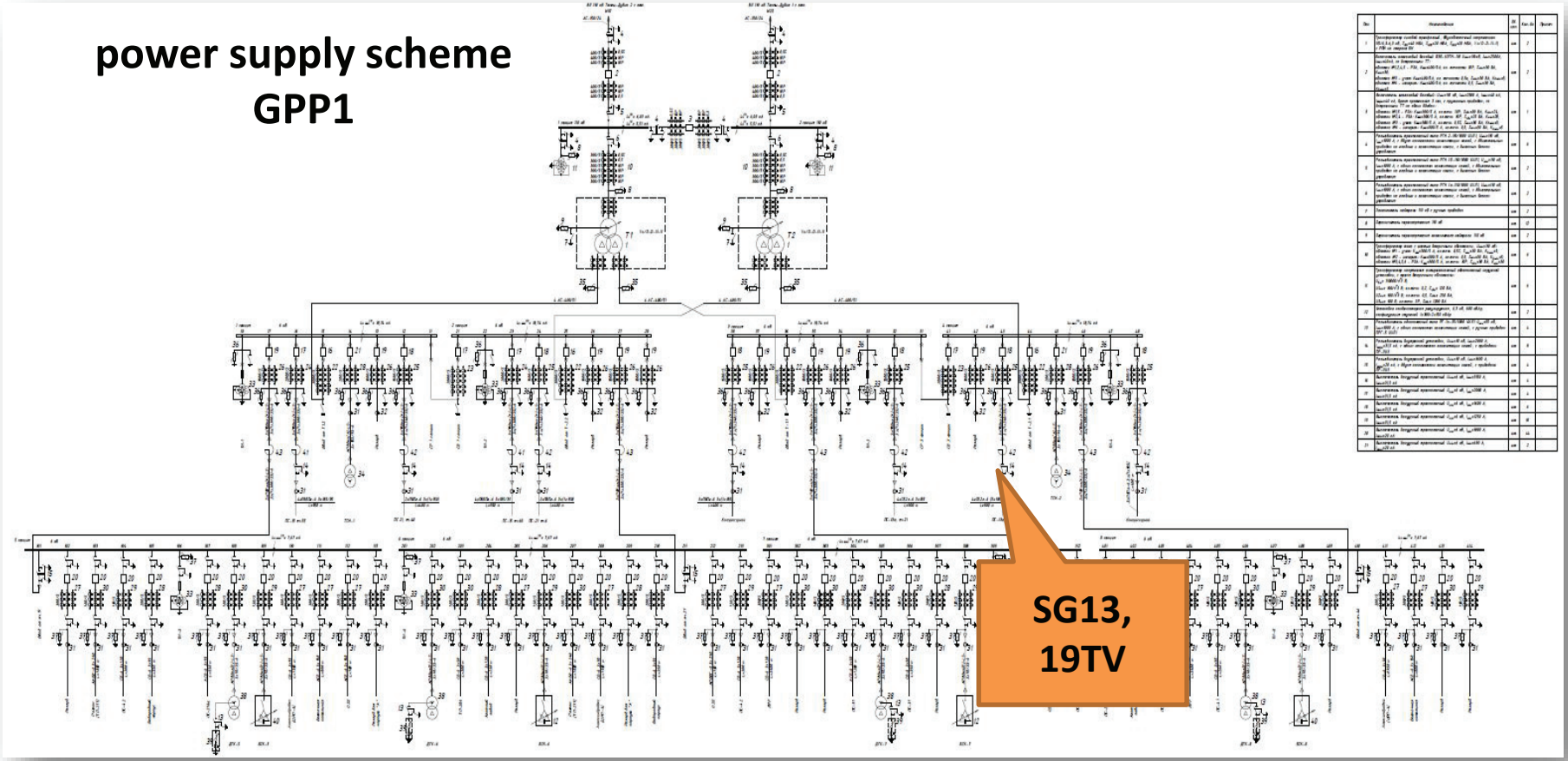

Nuclotron power supply System

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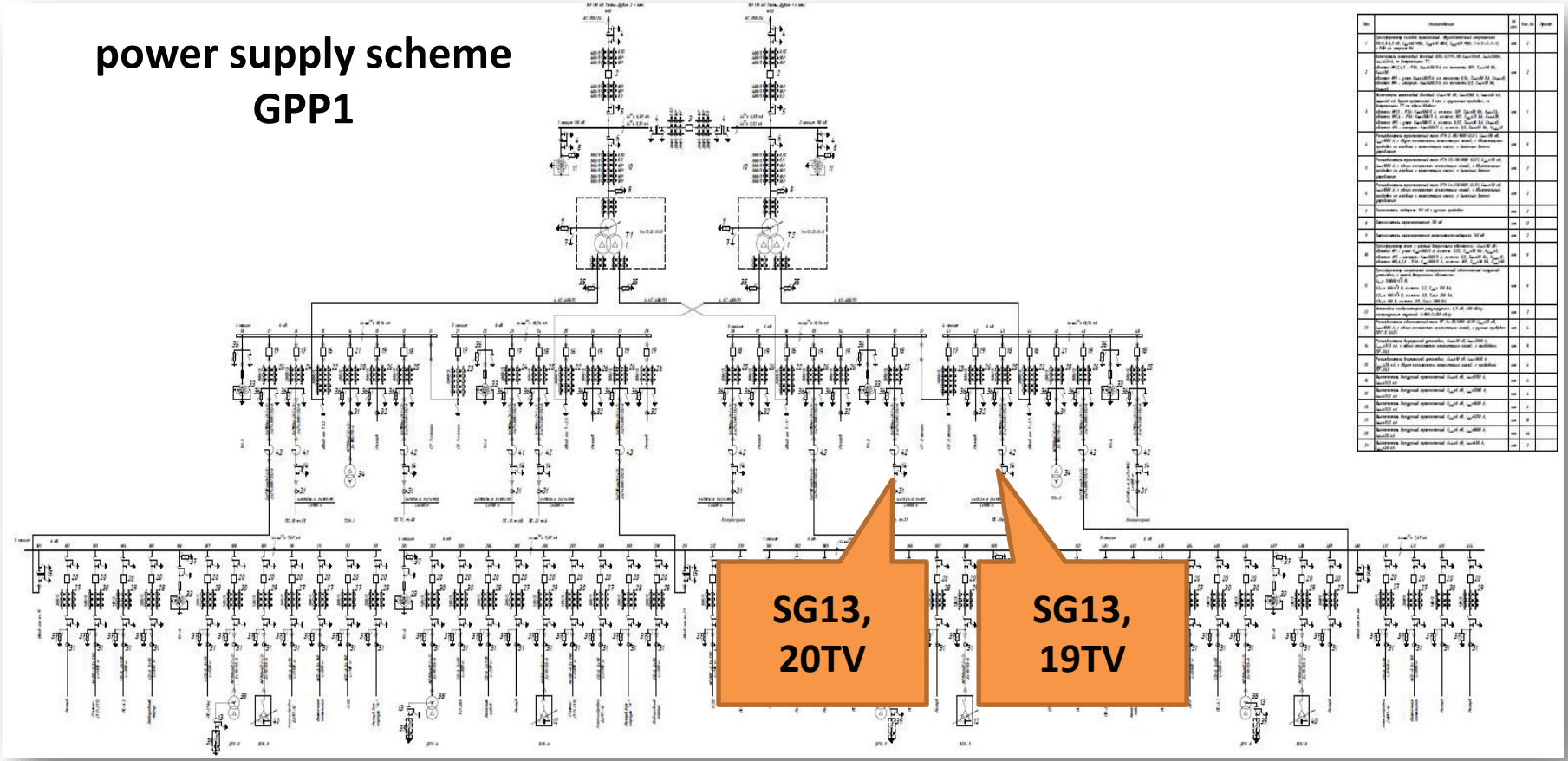


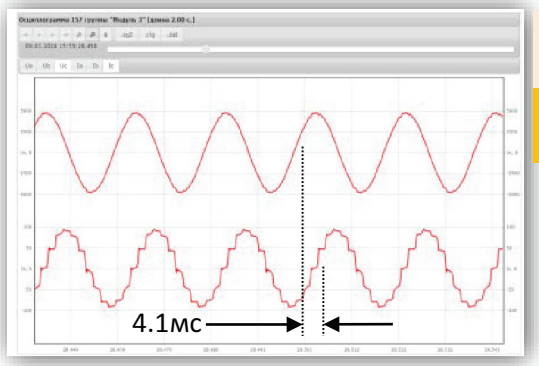
Nuclotron power supply System

Power consumption of the network is 6 kV

supply 19TV, nets 6kV

voltage waveform

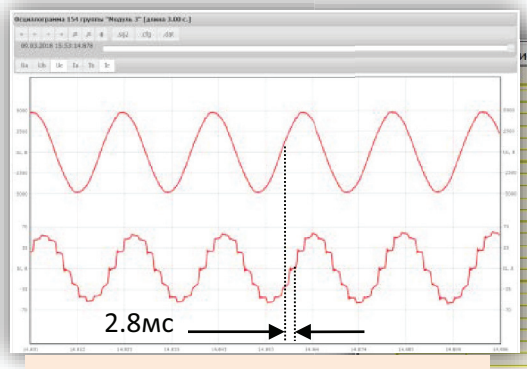
current waveform



amplitude Iac ~ 100A

cos (73.8) = **0.28**

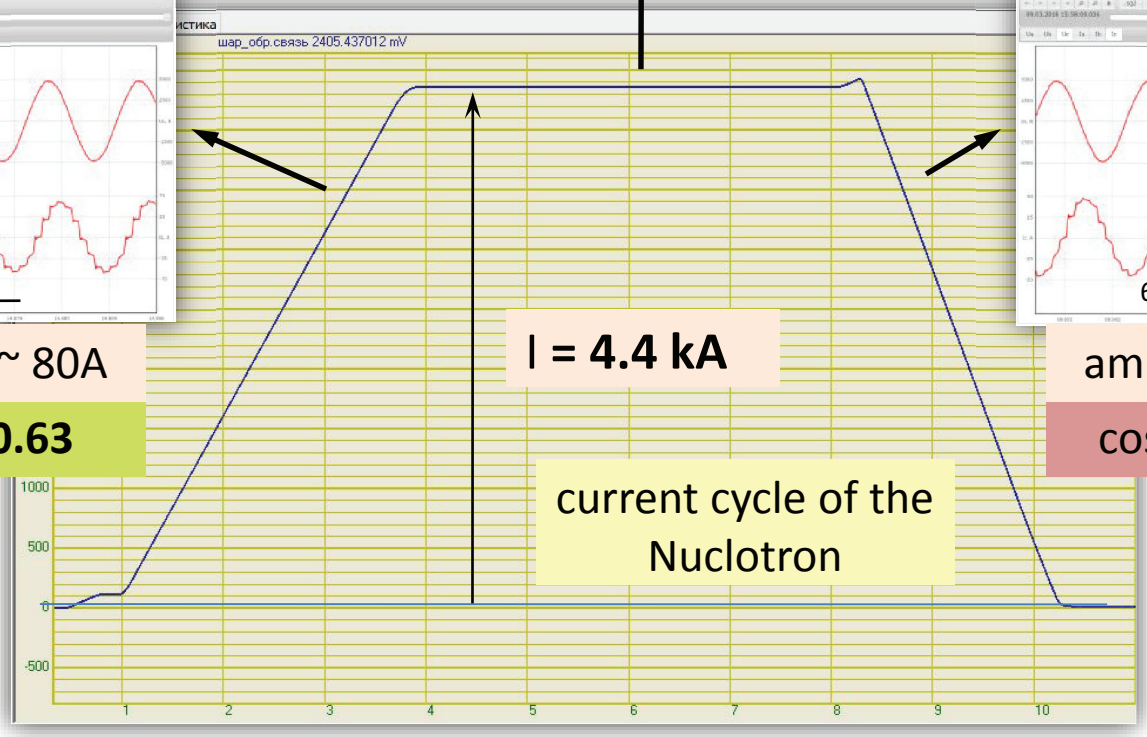
Current rise



amplitude Iac ~ 80A

cos (50.4) = **0.63**

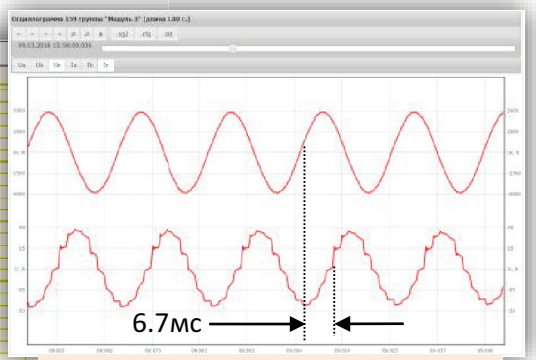
Current plateau



I = 4.4 kA

current cycle of the Nuclotron

Reduce current

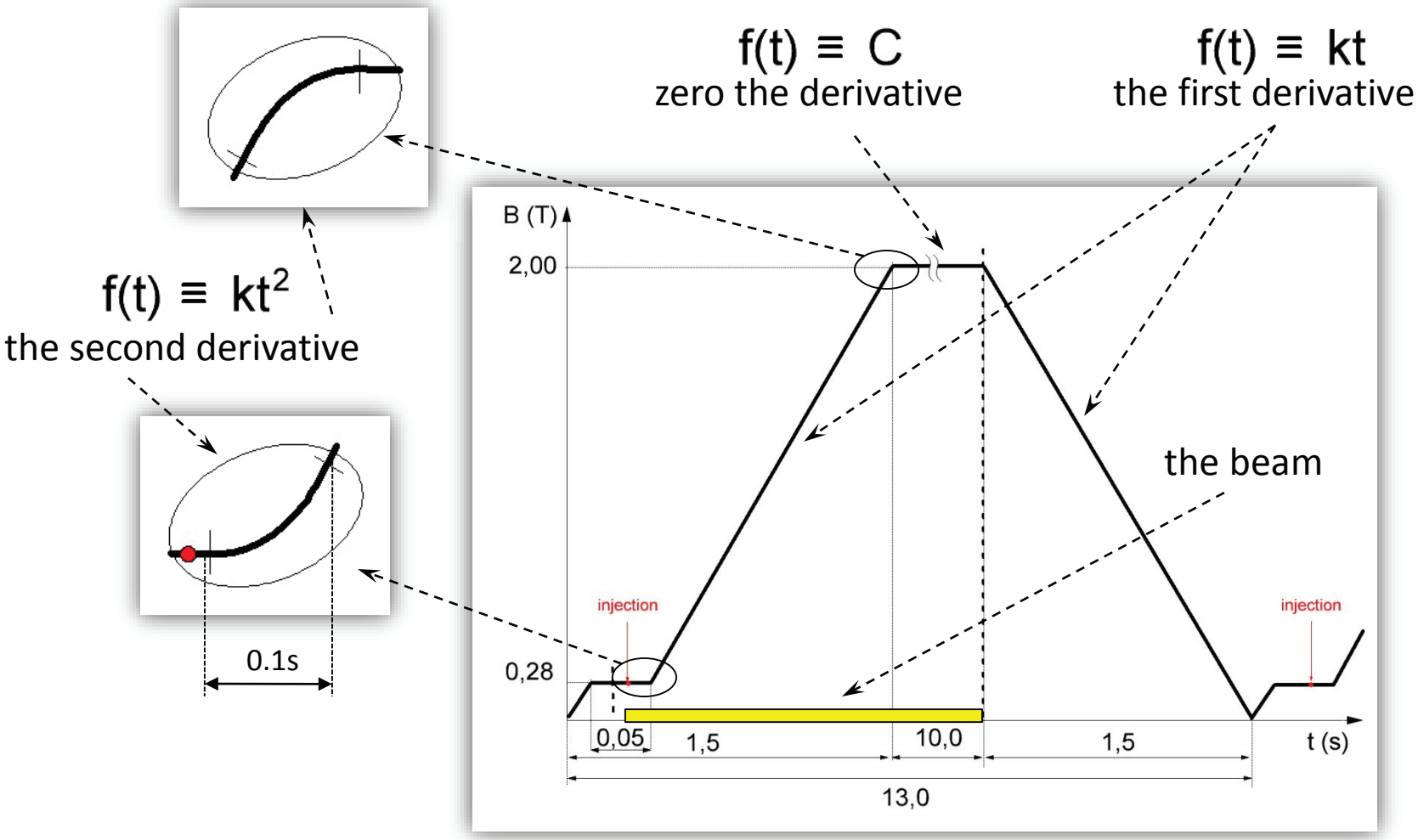


amplitude Iac ~ 80A

cos (120.6) = **-0.51**

Source current regulators

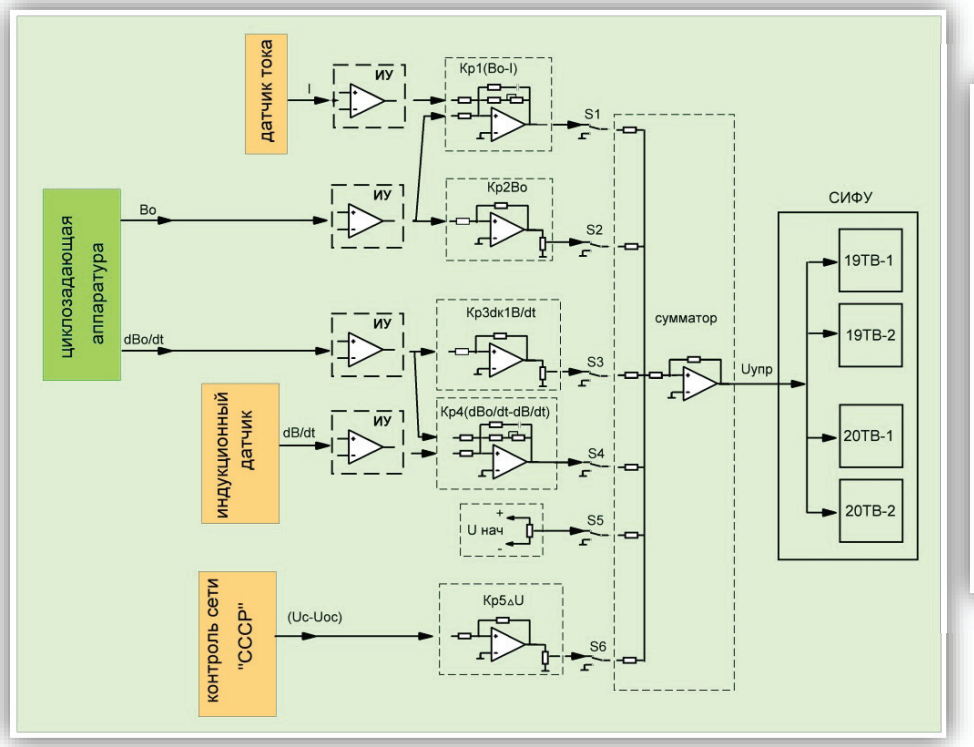
Reference function



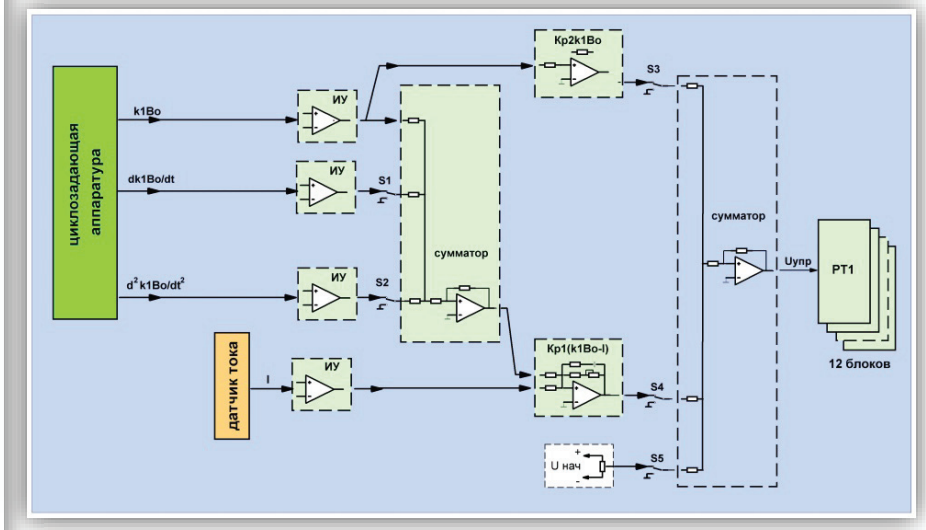
Source current regulators

Block diagram of the current regulator

19TV , 20TV

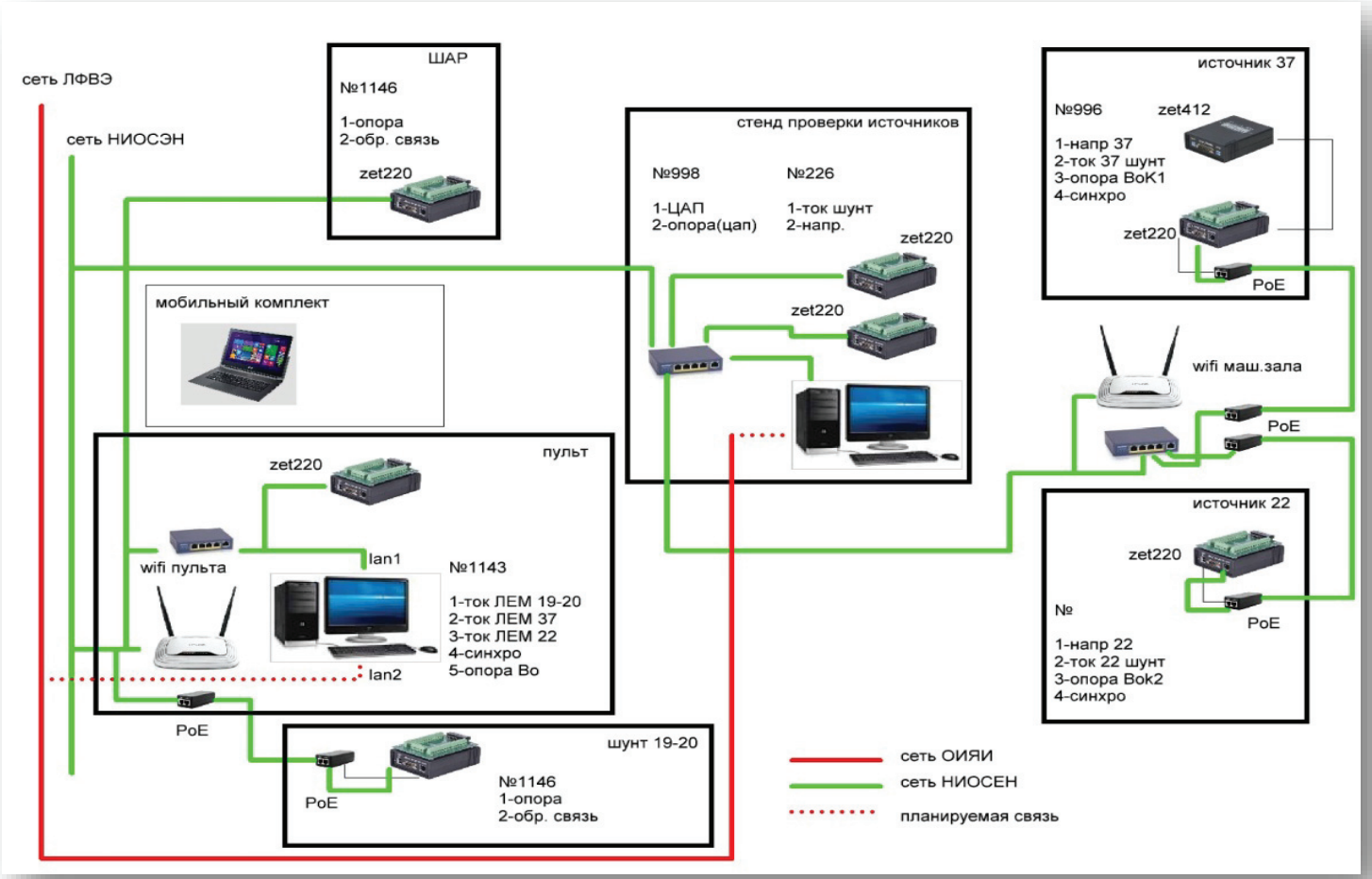


37TV



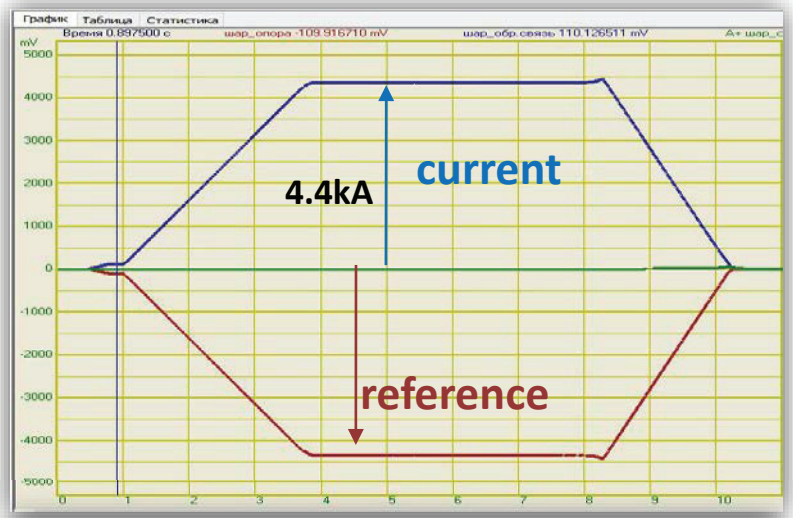
Source current regulators

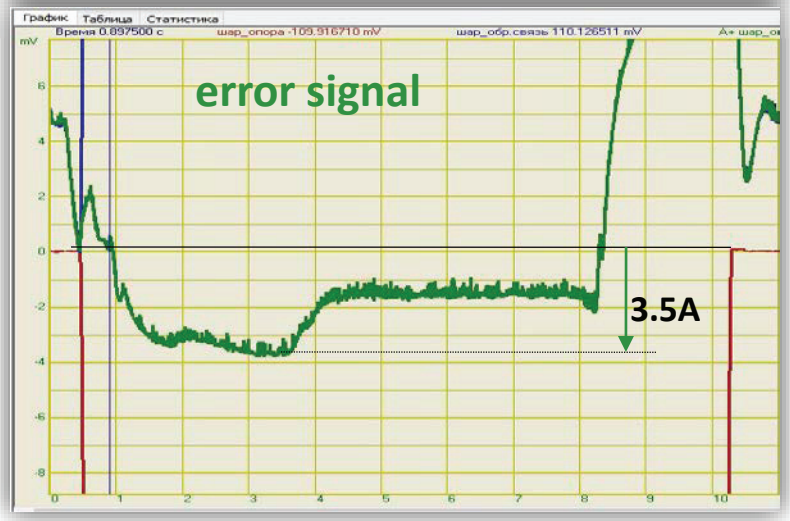
Precision current measurement subsystem based on the ZET 220



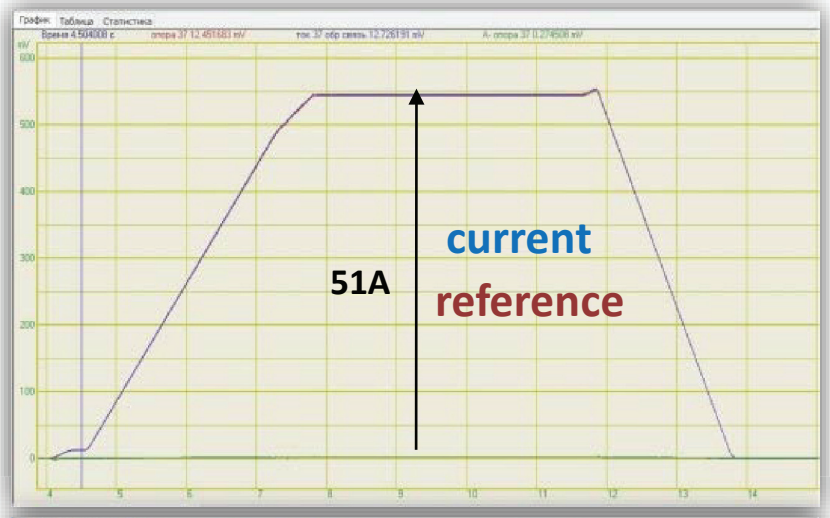
Source current regulators

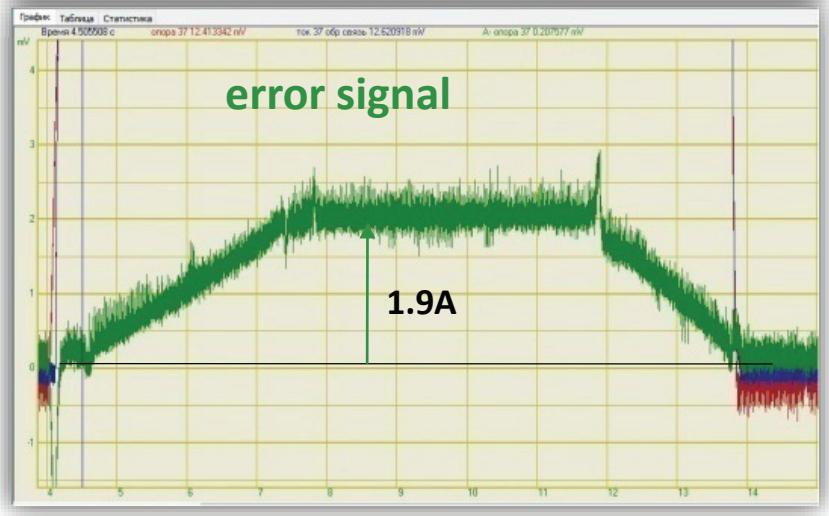
19TV 20TV



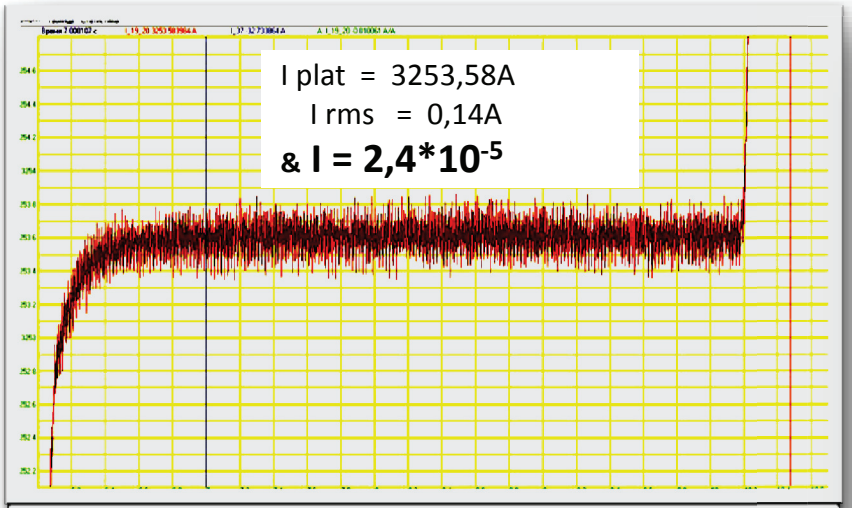


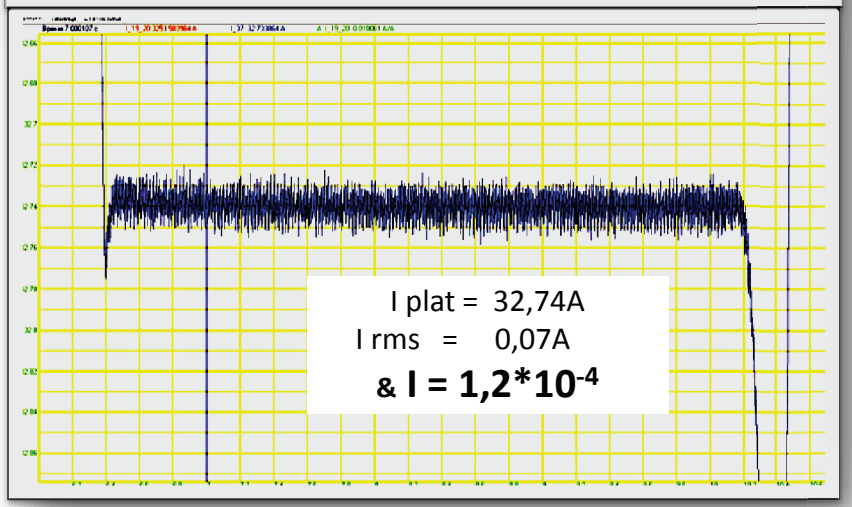
37TV

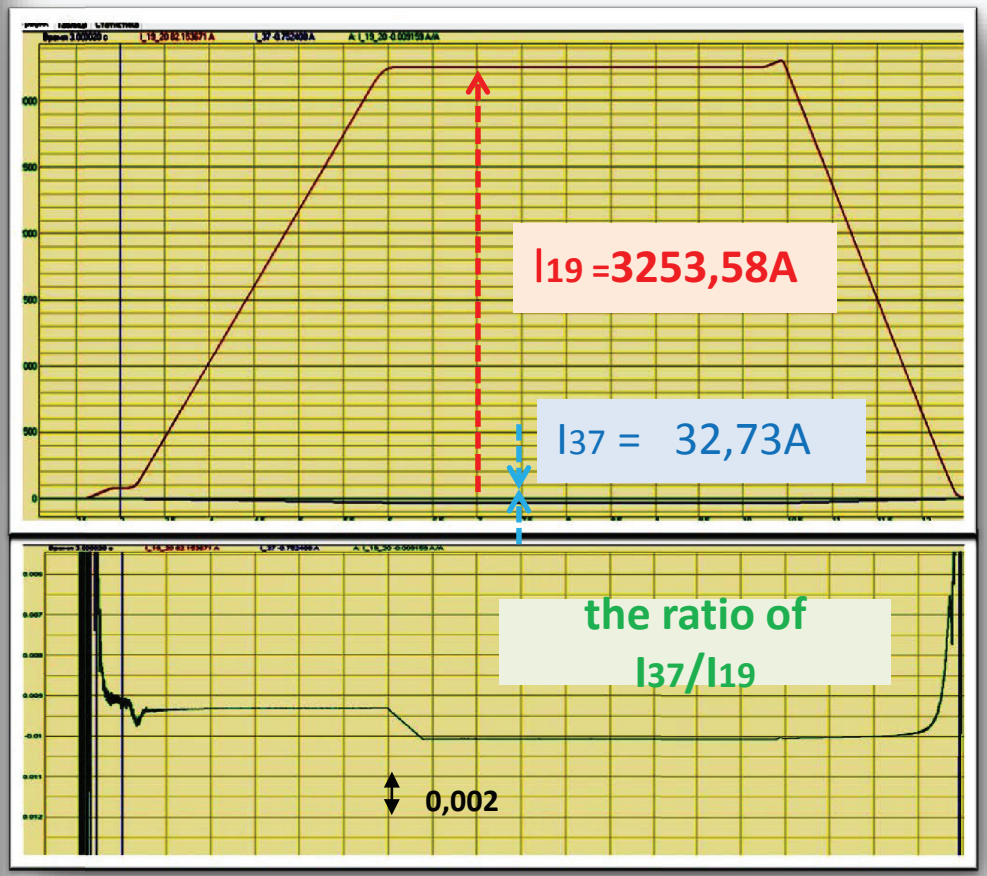




Precision currents





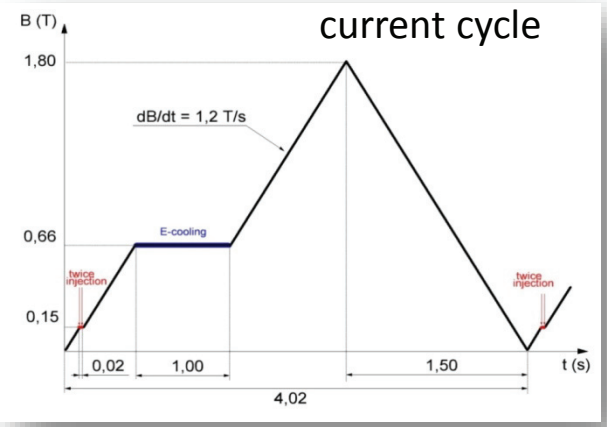


achieve repeatability of the injection magnetic field with an accuracy of +/-0.2 Gs or arelative accuracy of 2*10 -5

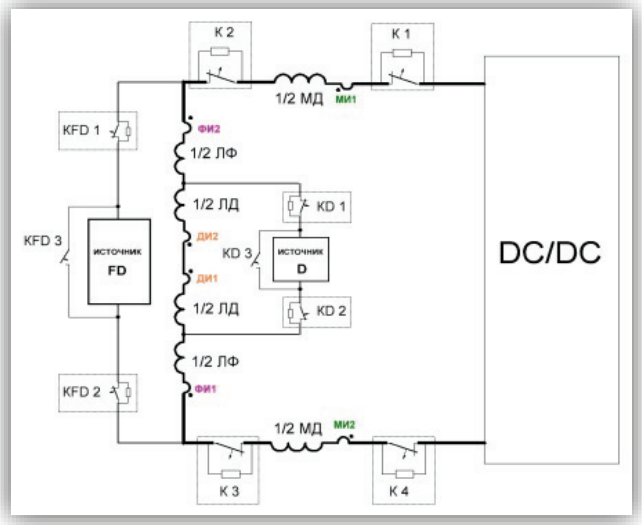
Booster power system

the main parameters of the PS

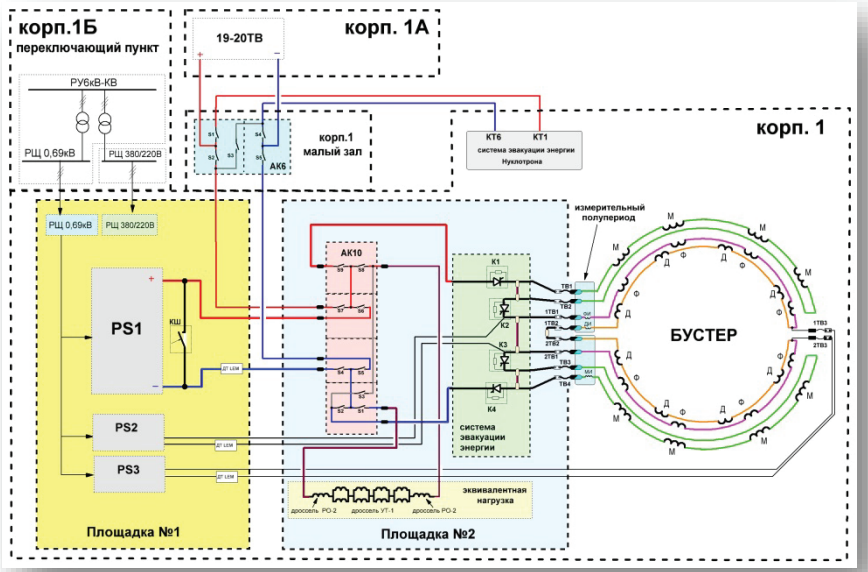
1	Maximum power	2,86 MW
2	Voltage	260V_{DC}
3	Current ($I_{макс.}$)	11000 A_{DC}
4	Relative stability of the current at di/dt= 0	$2*10^{-4}$
5	Relative stability of the current at di/dt = 0	$5*10^{-5}$
7	Operating modes	-static, - dynamic with dI/dt=0…+/-7 кА/с



Schematic diagram

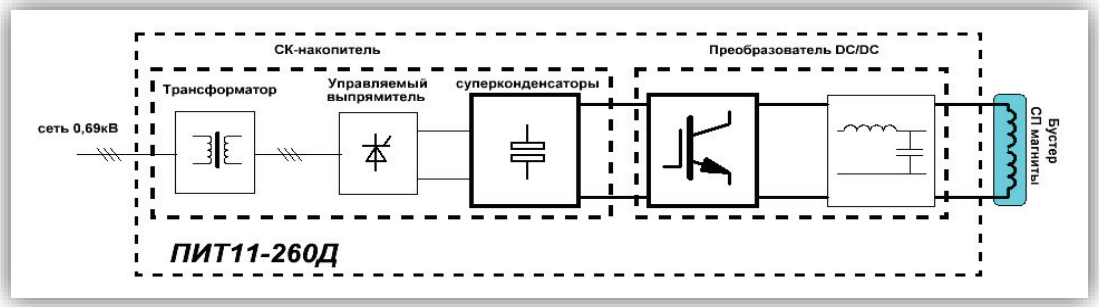


Wiring diagram



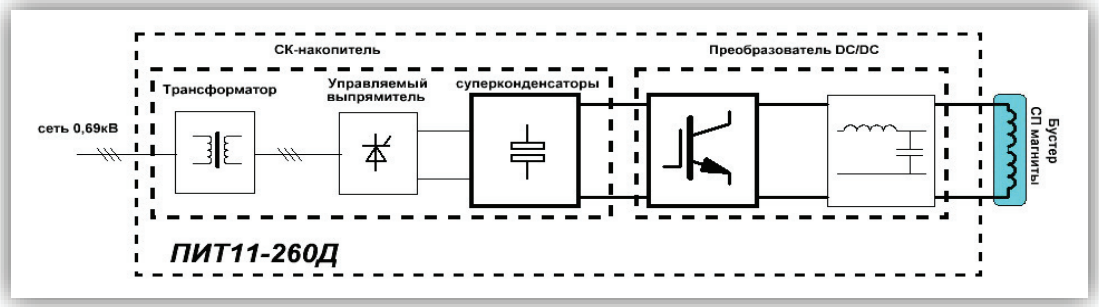
Booster power system

Block diagram of the current source

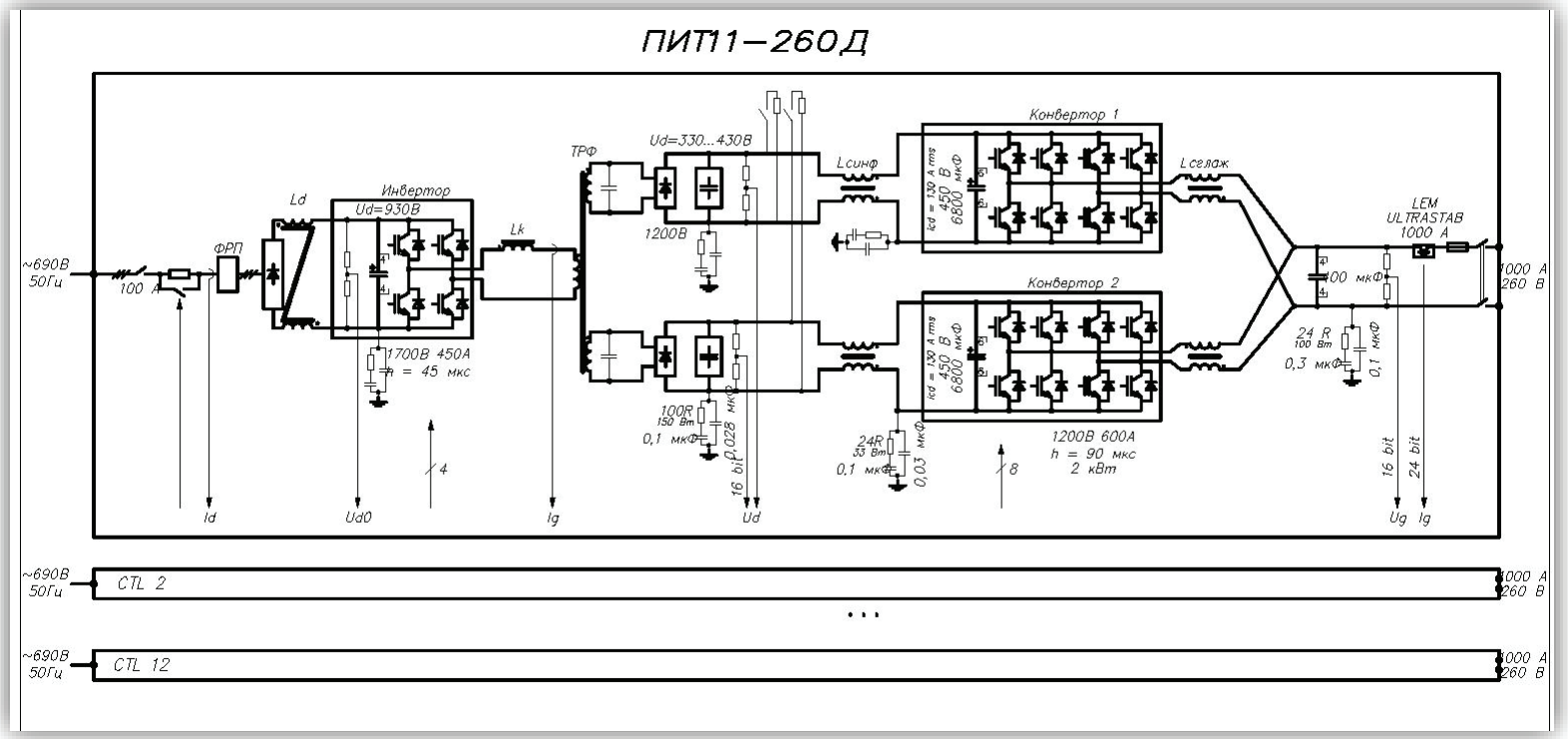


Booster power system

Block diagram of the current source



Schematic diagram of the current source ПИТ11-260



Production «НПП ЛМ Инвертор», Moscow, Russia

Booster power system

System energy evacuation from the SC-magnets

Requirements for the system of energy evacuation from the SC-magnets of the Booster

1) energy output constant - **160ms,**
2) the potential of the magnetic elements relative to the "earth" - **not more than 500V,**
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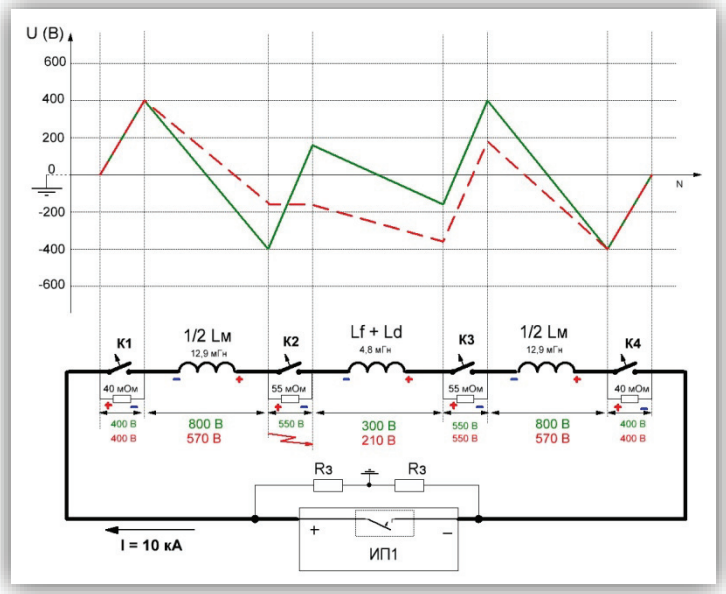
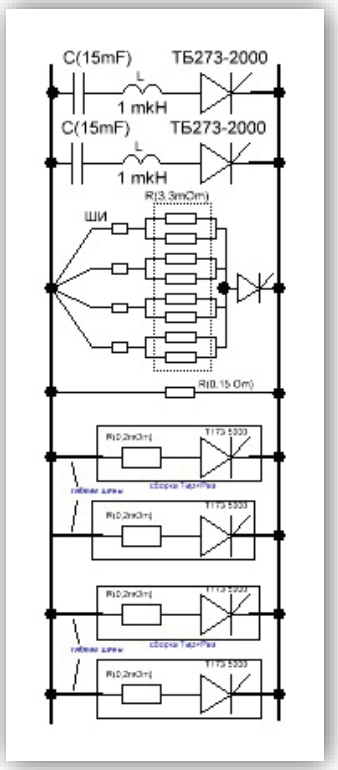
Potential graphics



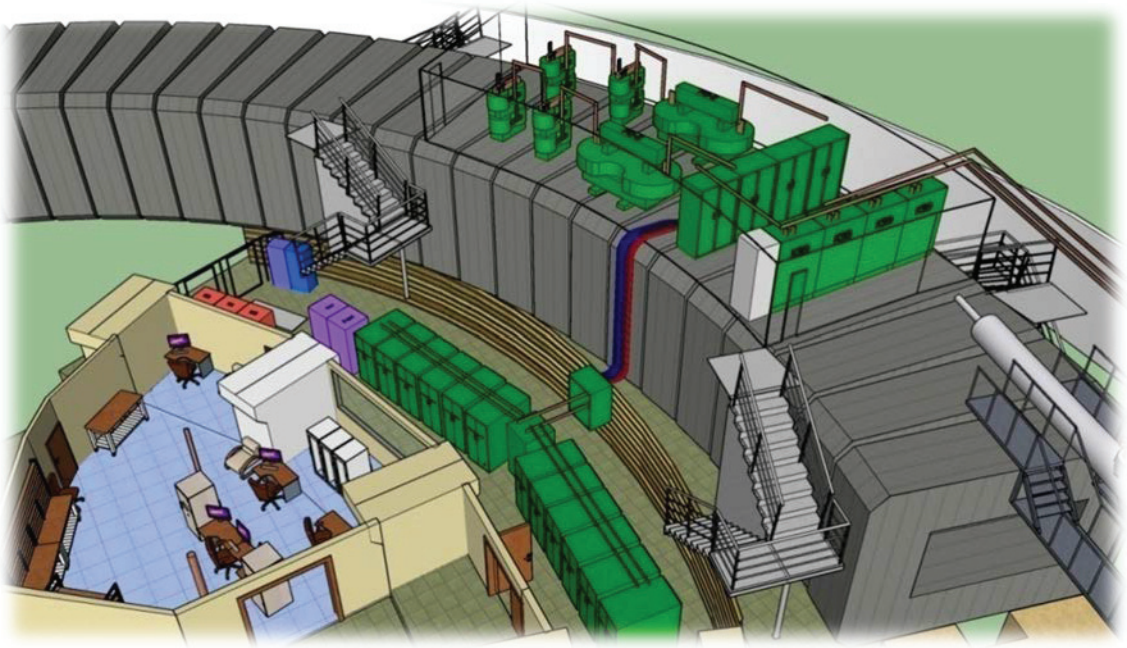
Schematic diagram



Common view

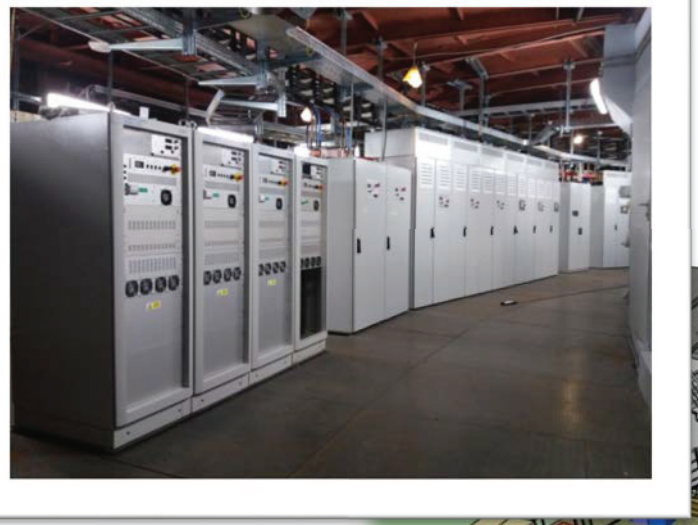
Booster power system

Bld.1

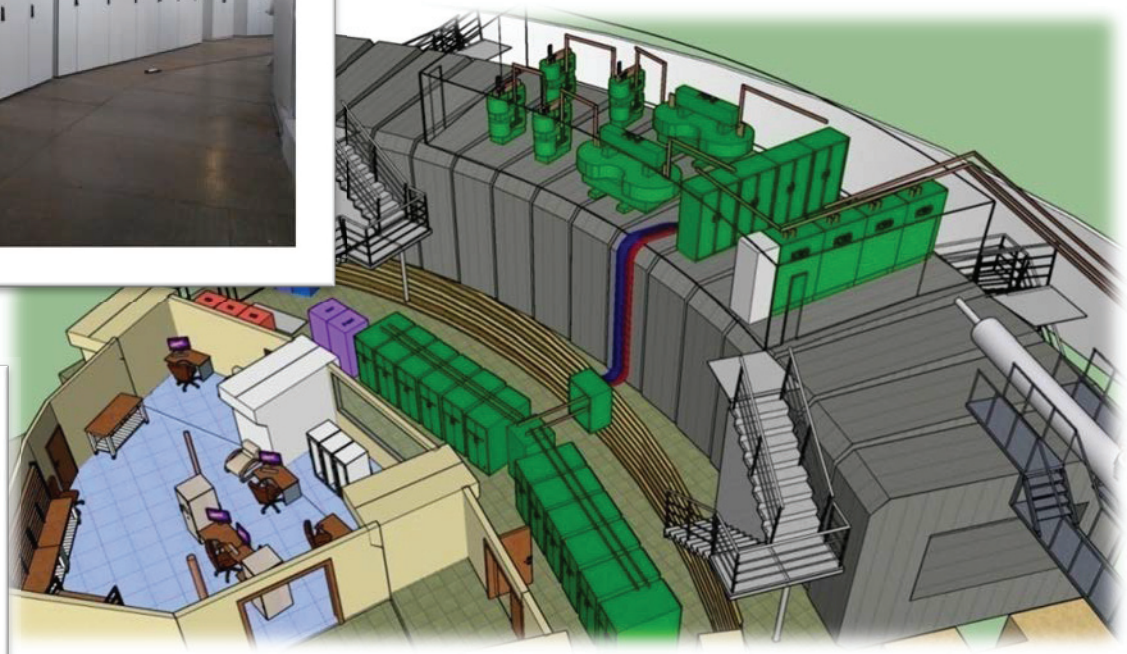


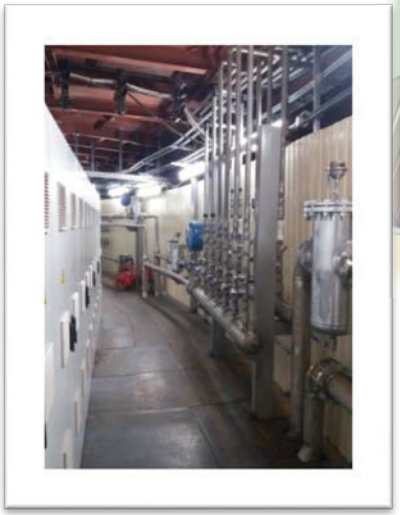
25

Booster power system



Bld.1

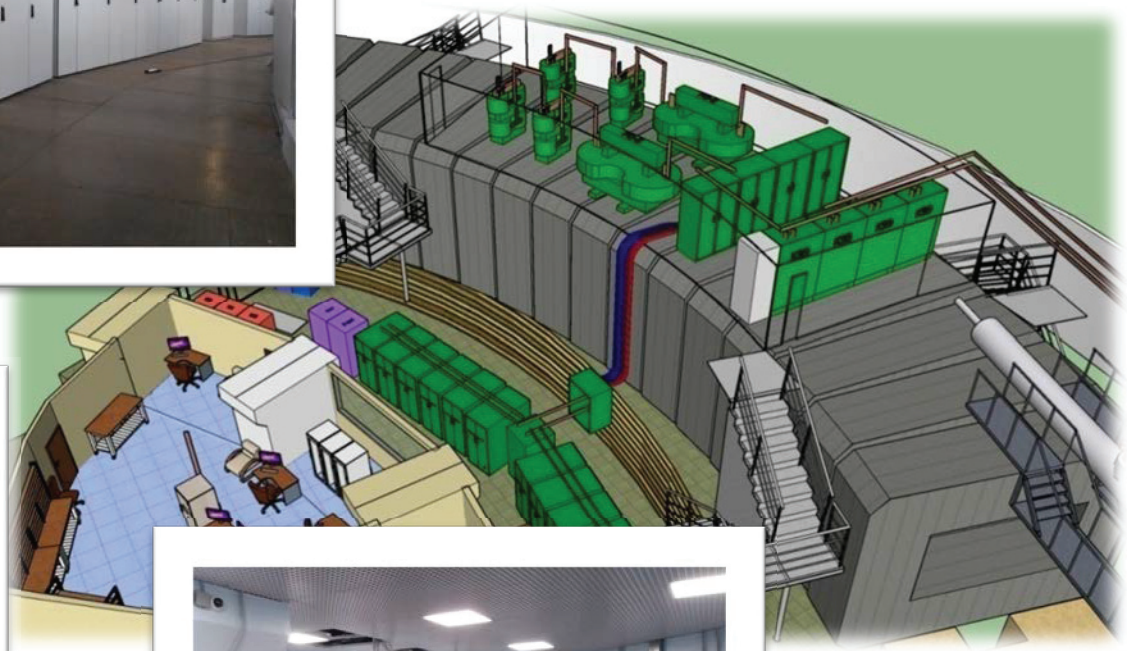


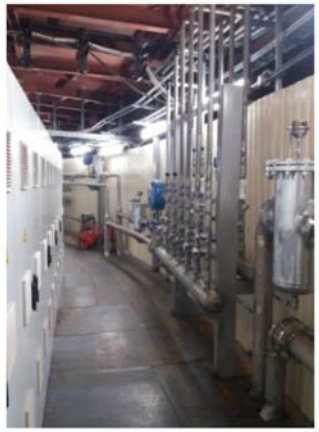


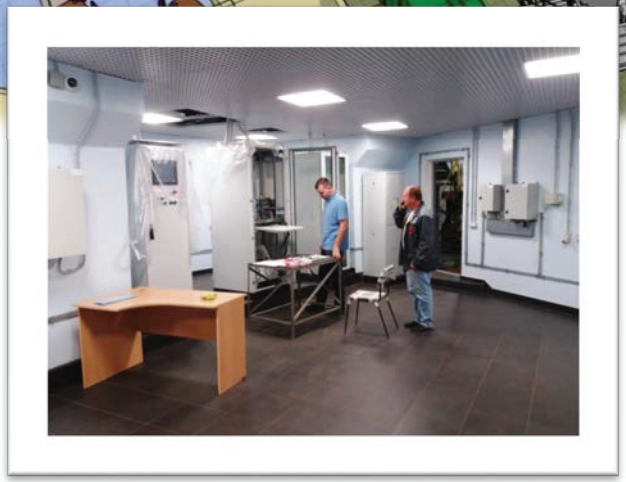
26

Booster power system

Bld.1



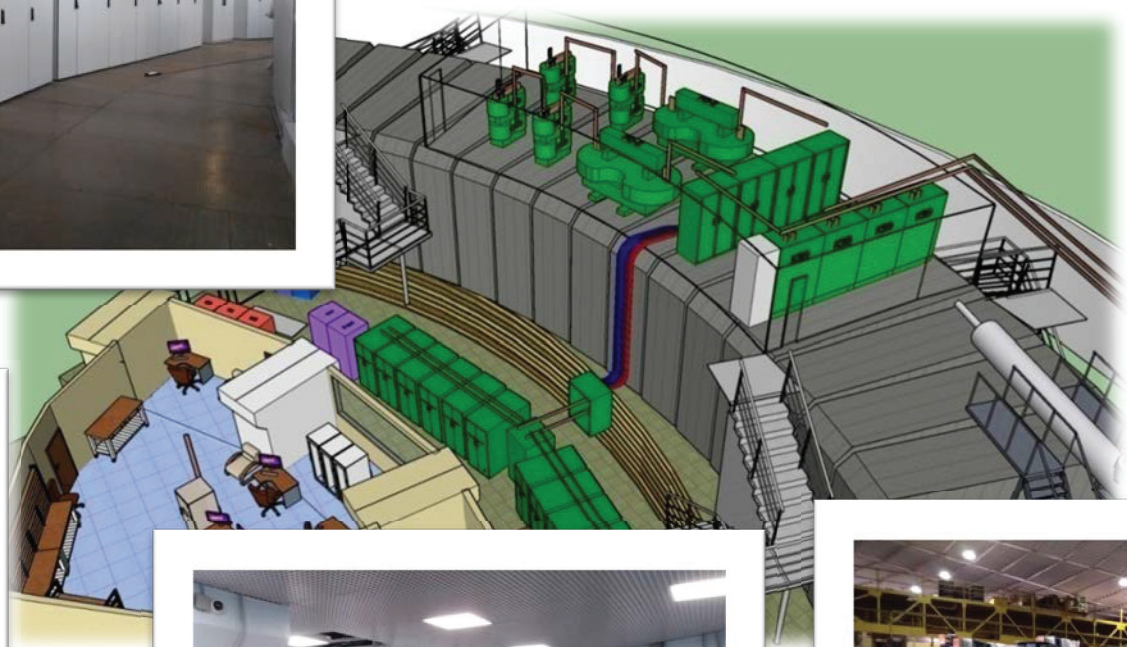


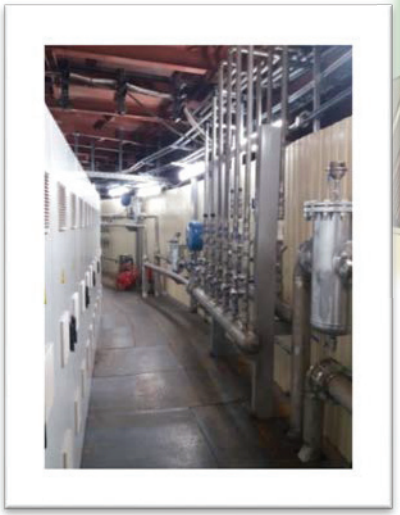


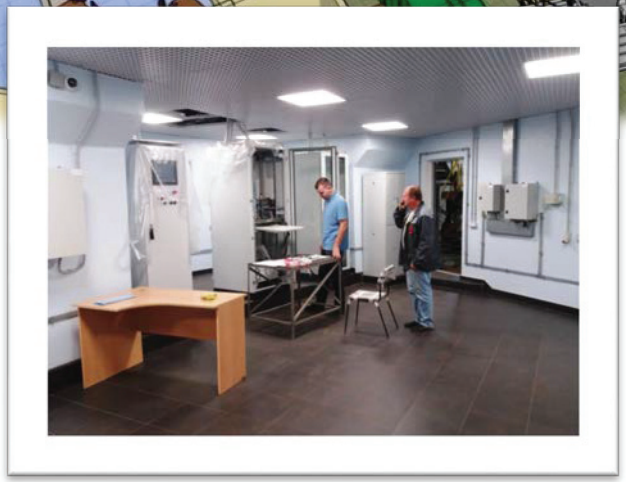
27

Booster power system

Bld.1

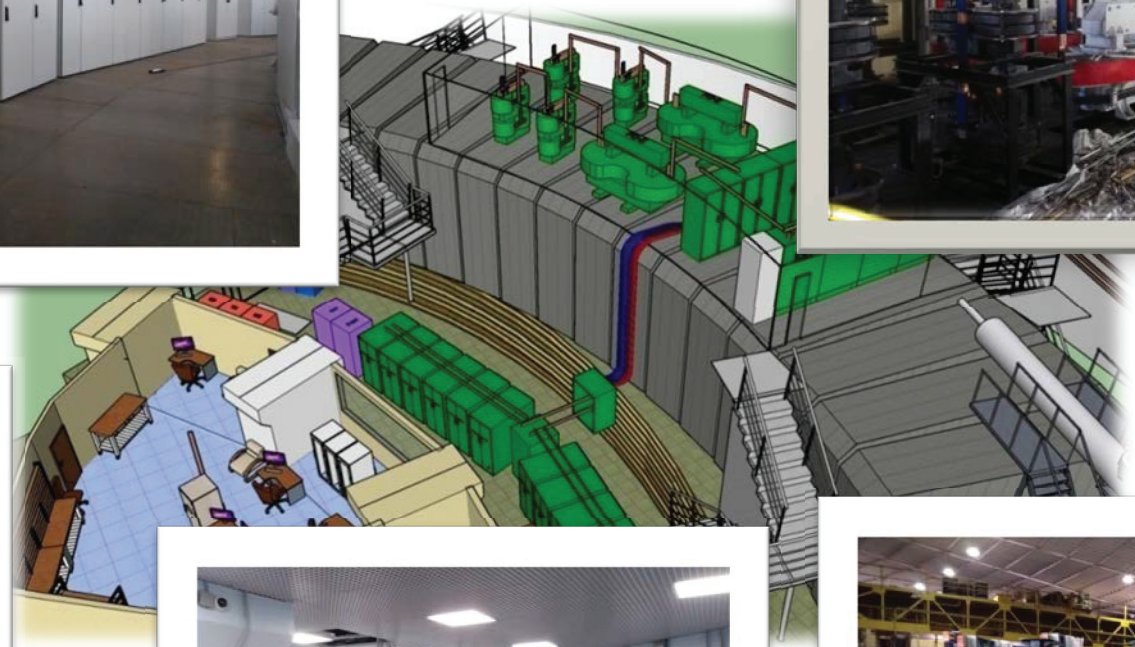


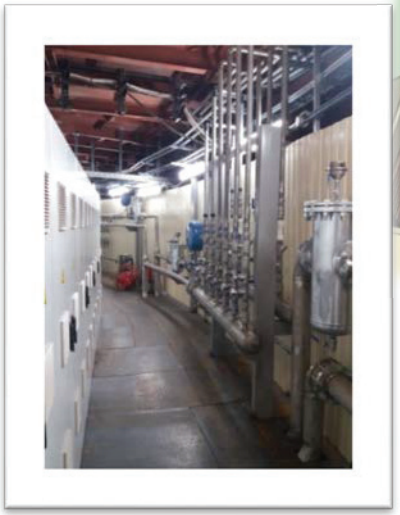


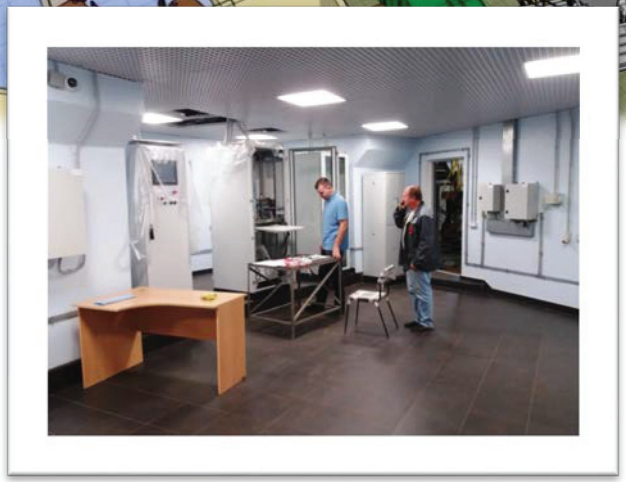


Booster power system

Bld.1

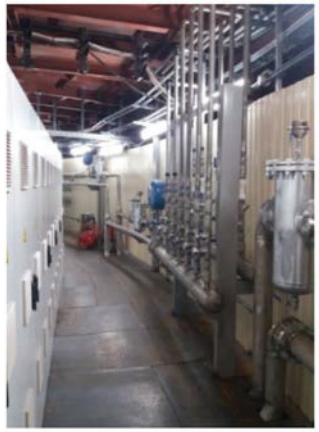






Booster power system

Start-up ПИТ11-260
27 july 2019г
900А!

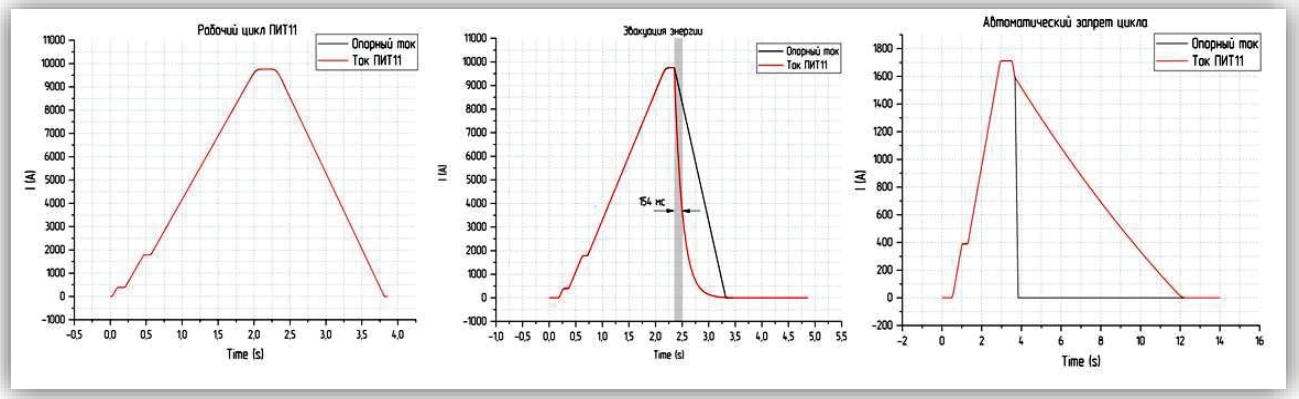


Booster power system

Technological modes

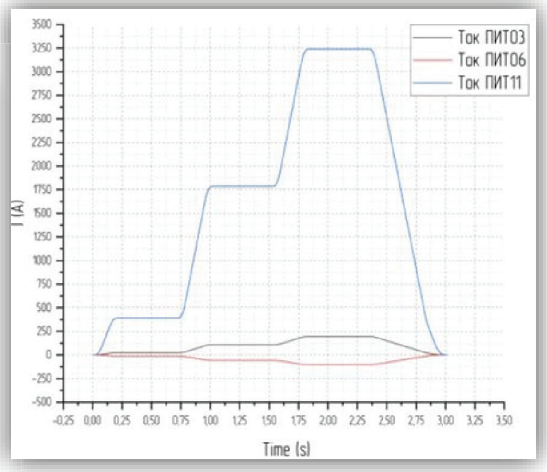
1 session dec. 2020

cycle | energy evacuation | emergency cycle

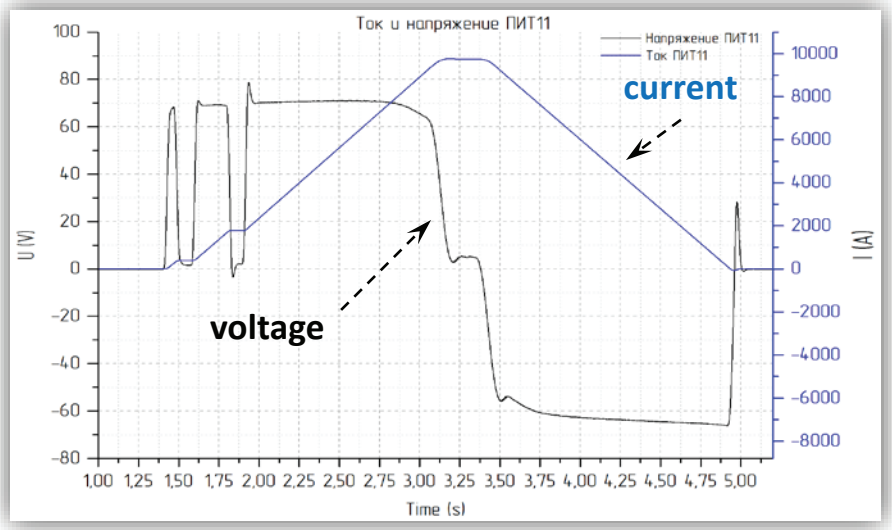


2 session sept. 2021

current ПИТ11, ПИТ06, ПИТ03



Project cycle 9,7kA ПИТ11



Power consumption

switchboard ПИТ11, nets 0.69kV

Ptot = 88kW

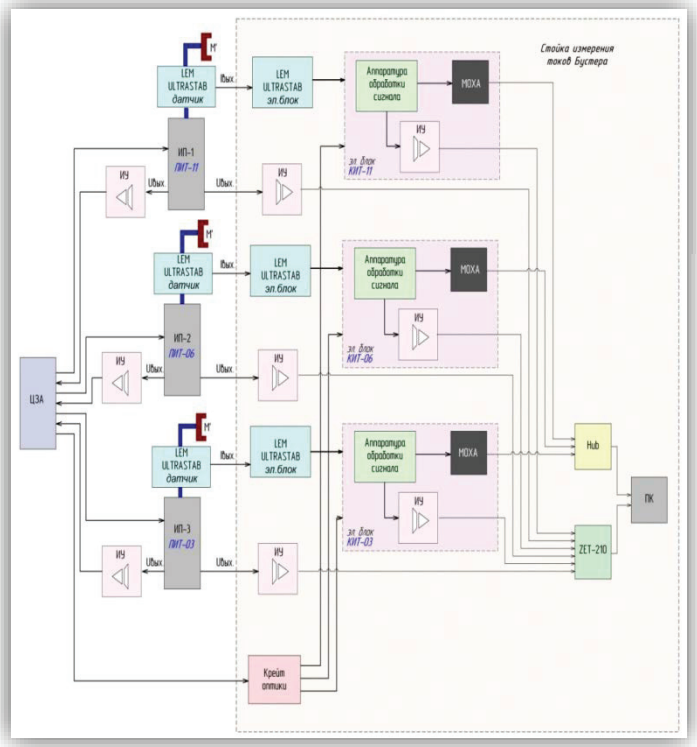
Qtot = 84kVA

Stot = 121kVA

Booster power system

Precision current measurement subsystem

Functional diagram of the measurement system



The main parameters of the system:

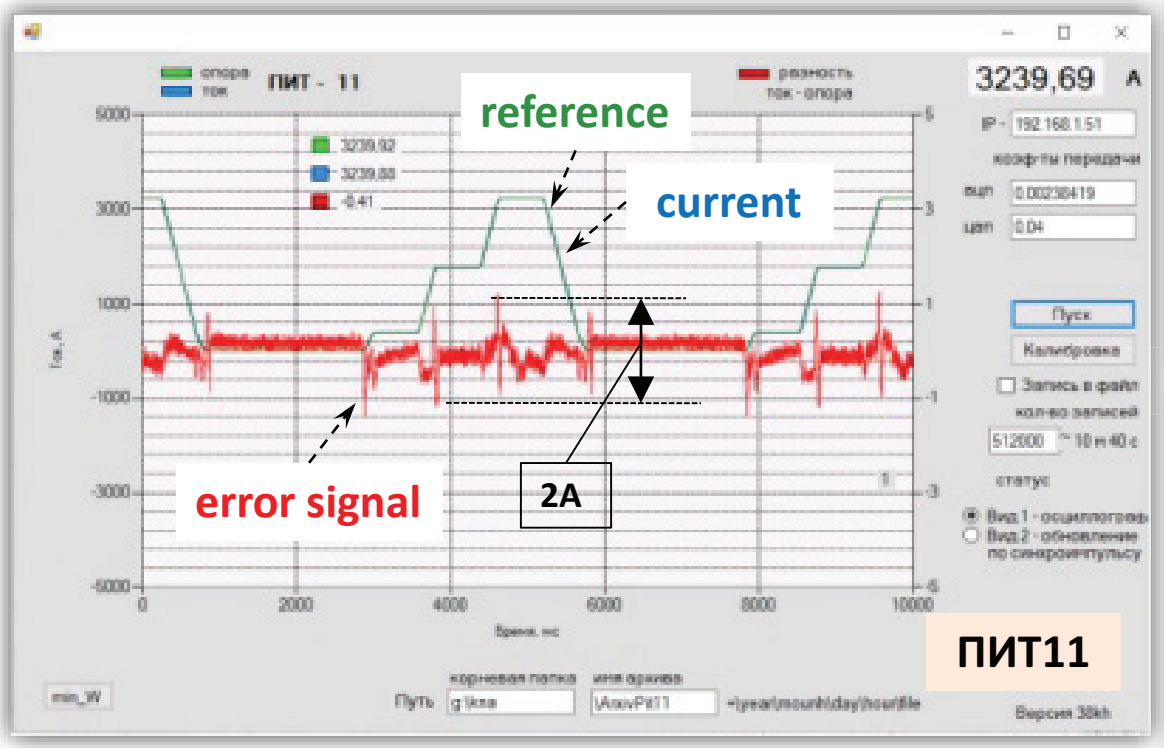
- the measurement range of the primary current: from 0.1 to 10kA;
- accuracy of current measurement in static mode: for the main source 10kA **– 60ppm**, for additional sources 600 A and 300 A **– 20ppm**;
-- accuracy of current measurement in dynamic mode:• for the main source **– 100ppm**,• for additional sources (600 A and 300 A) – **20ppm**;
-– the frequency of current measurement is **800Hz**

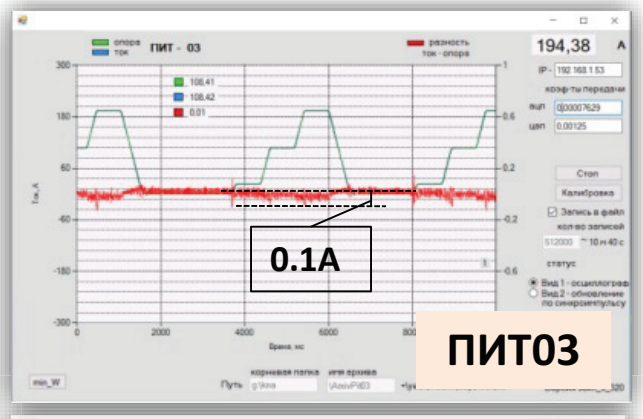
general view of the measuring equipment

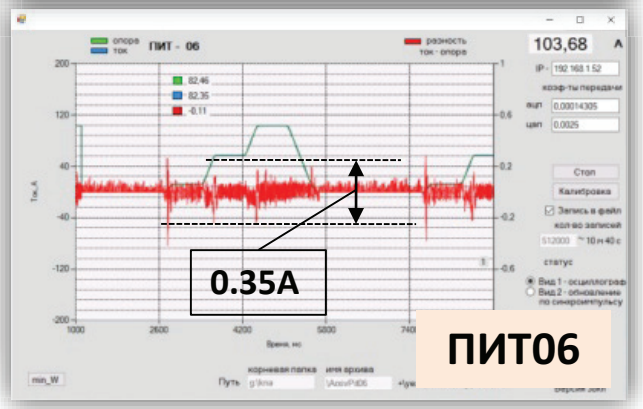
Booster power system

Precision current measurement subsystem

2 session sept. 2021







PS	The average value of the current deviation from the reference (RMS) A	Relative current error ppm	Relative error of current repeatability from cycle to cycle ppm
ПИТ11	**0,17129**	**18**	**7**
ПИТ06	**0,00647**	**11**	**46**
ПИТ03	**0,00459**	**16**	**27**

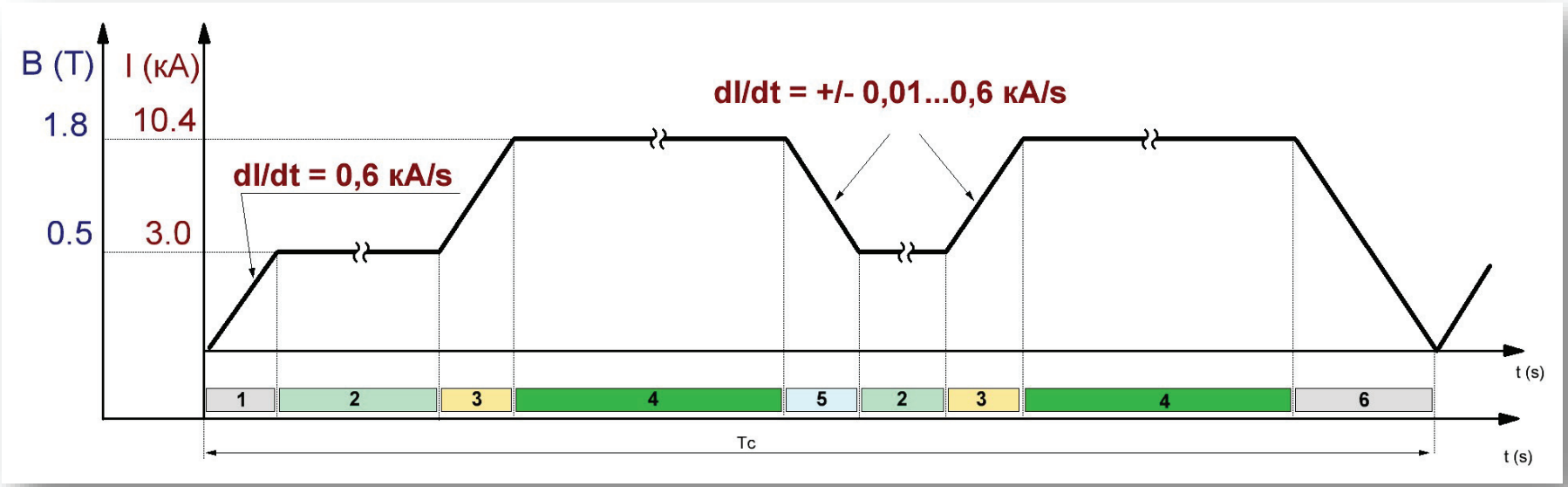
33

Main parameters of the structural superconducting magnets

The inductance of the dipole magnets, Lm	мН	36
The inductance of the quadrupole focusing magnets, Lf	мН	4,6
The inductance of the quadrupole defocusing magnets, Ld	мН	4,6
The current of the dipole magnet with a field of 1.8 T, Im	кА	10,4
Current stability, ΔIm/ Im		$2*10^{-5}$
The current of quadrupole focusing magnet with gradient field, If	кА	10,4
Voltage at the rate of change of the magnetic field 0.1 T/s, U	V	26

Power system requirements

The cycle of the magnetic field / current



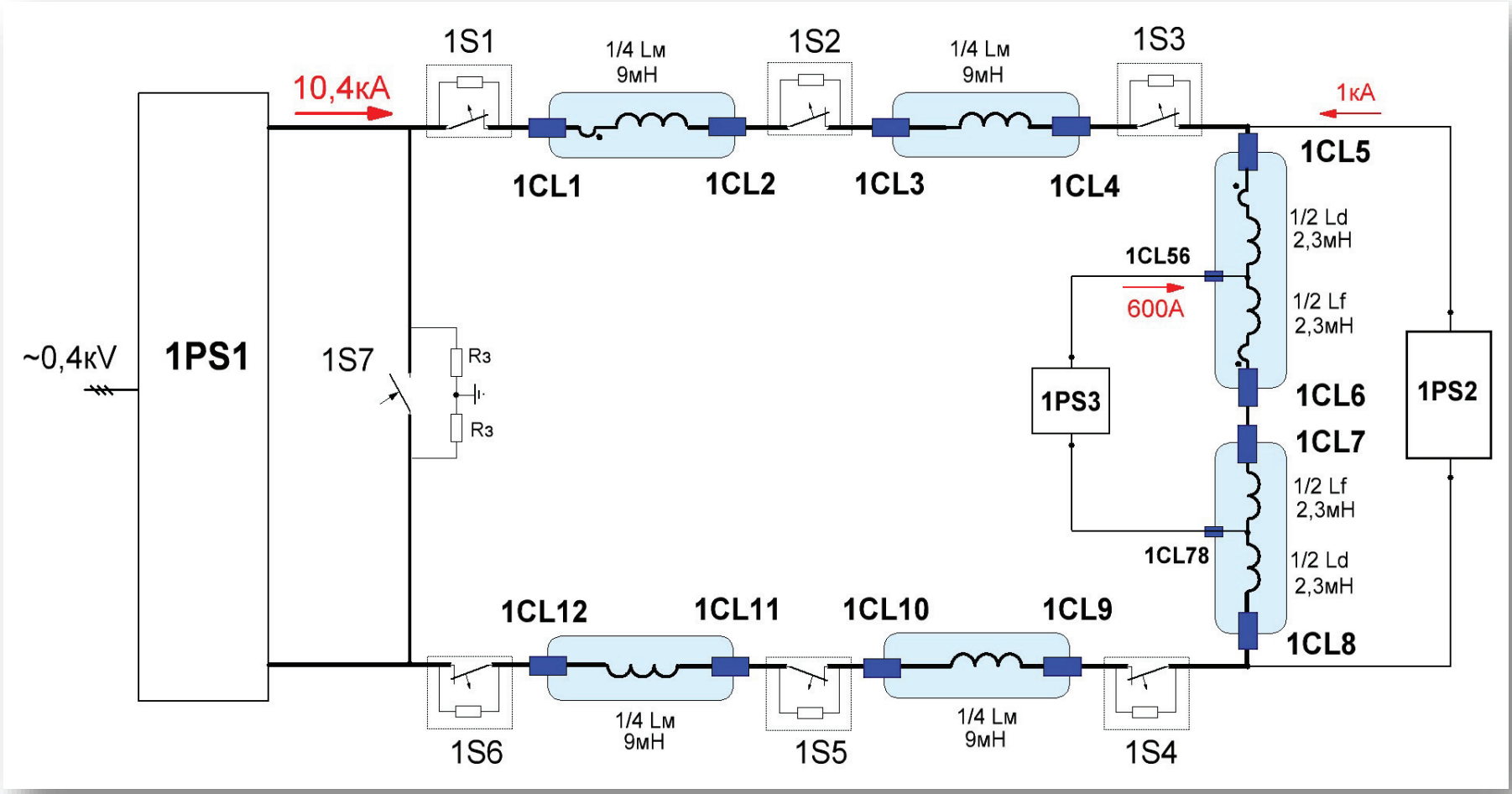
Requirements for the system of energy evacuation from the SC-magnets of the Collider

1) energy output constant - **160ms,**
2) the potential of the magnetic elements relative to the "earth" - **not more than 500V,**
3) **reliability.**

35

The power supply system of the Collider

Schematic diagram



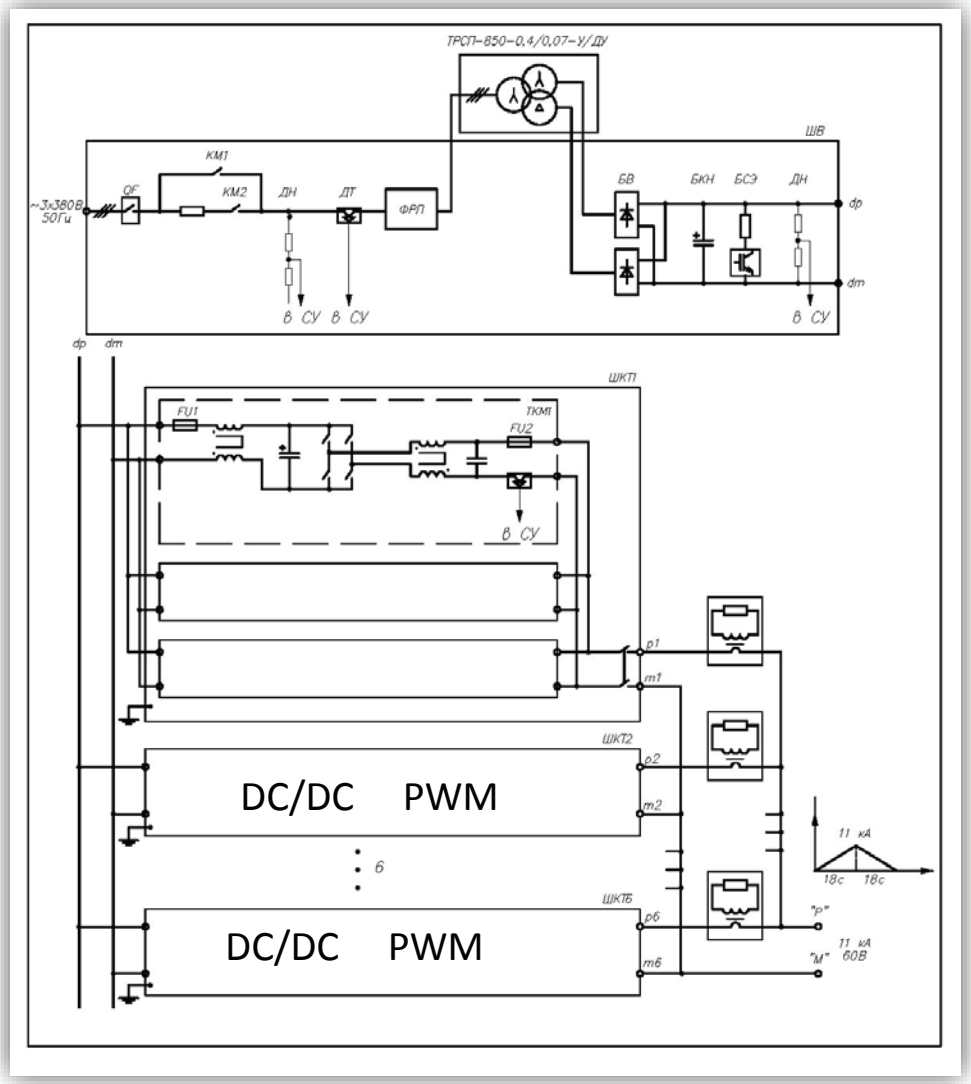
Main parameters of power supplies

	PS1	PS2	PS3
Supply voltage	3ϕ ~50Hz 380В +/-10% TN-S		
Maximum power,	**600 кW**	45 кW	25 кW
Average power, not more than	**250 кW**	20 кW	10 кW
Source voltage	+/-50 V_{DC}	+/-40 V_{DC}	+/-30 V_{DC}
Output current	**11000 A_{DC}**	**1000 A_{DC}**	**600 A_{DC}**
The inductance of the load	45 мН	9,2 мН	4,6 мН
ΔI/I at di/dt not equal to zero	**$2*10^{-4}$**	**$5*10^{-4}$**	**$5*10^{-4}$**
The minimum duration of rise/fall field	18 s		
ΔI/I at di/dt=0	**$2*10^{-5}$**	**$2*10^{-4}$**	**$2*10^{-4}$**
The maximum length of a table field with a di/dt=0	24 h		
Operating mode: -statics, - speaker dI/dt	yes 0…+/- 600 A/s	yes 0…+/- 60 A/s	yes 0…+/- 20 A/s

37

Power supplies

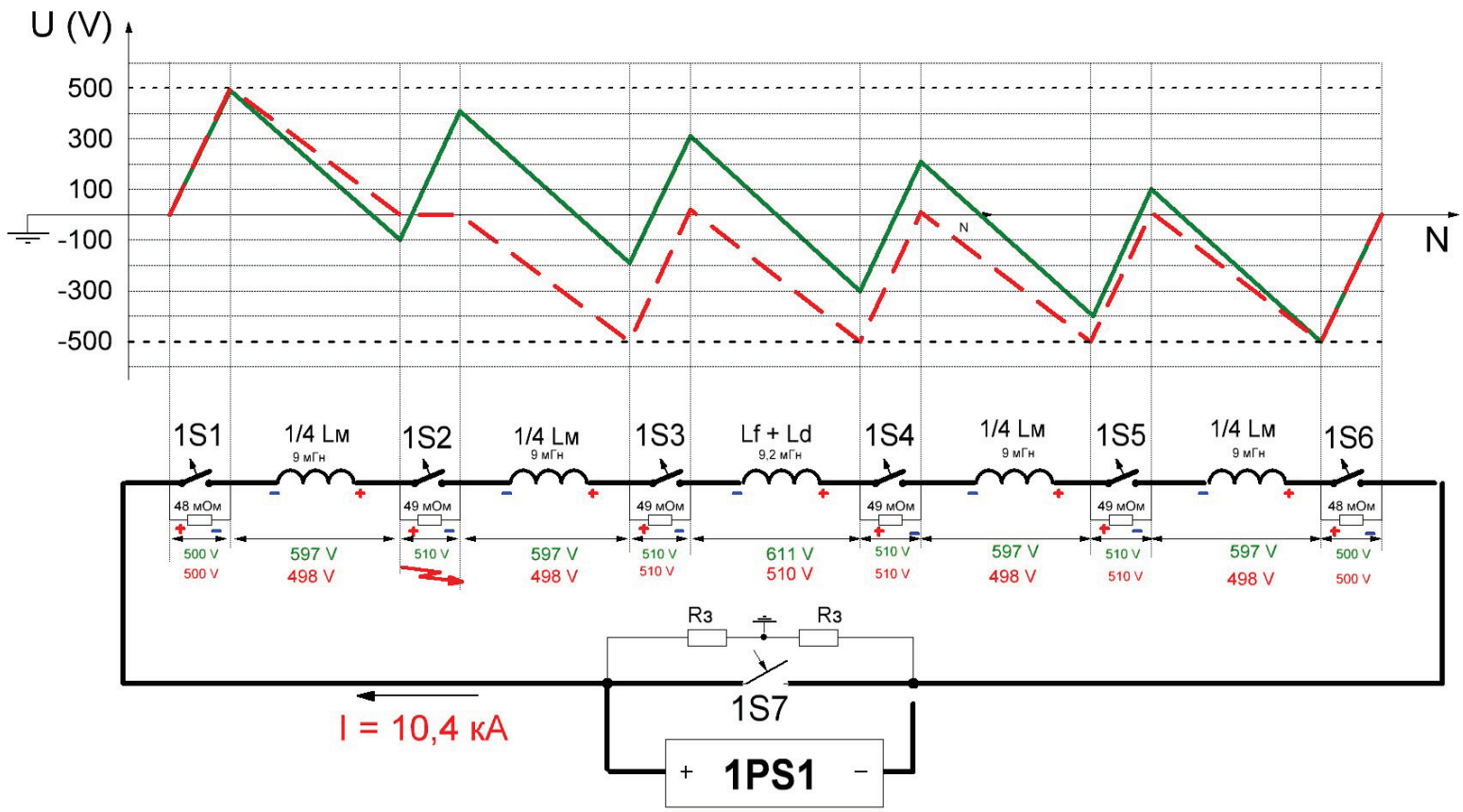
Schematic diagram of main source



Production

Production «НПП ЛМ Инвертор»

System energy evacuation from the SC-magnets



Parameters of energy output:	nominal	Emergency (shorted 1S2):
- time constant of output power	160мs	187 ms
- the total resistance of the field suppression of	0.29 om	0,241 om
- the total max voltage at the output	3000 V	2506 V

39

Energy evacuation Switch

Main parameters : 1) Static mode
2) Minimal energy loss
3) Operational reliability.

General view ВАБ49

Switch automatic high-speed ВАБ49-6300:

rated current - 6300A
rated voltage - 1050V
the off - time of 8ms

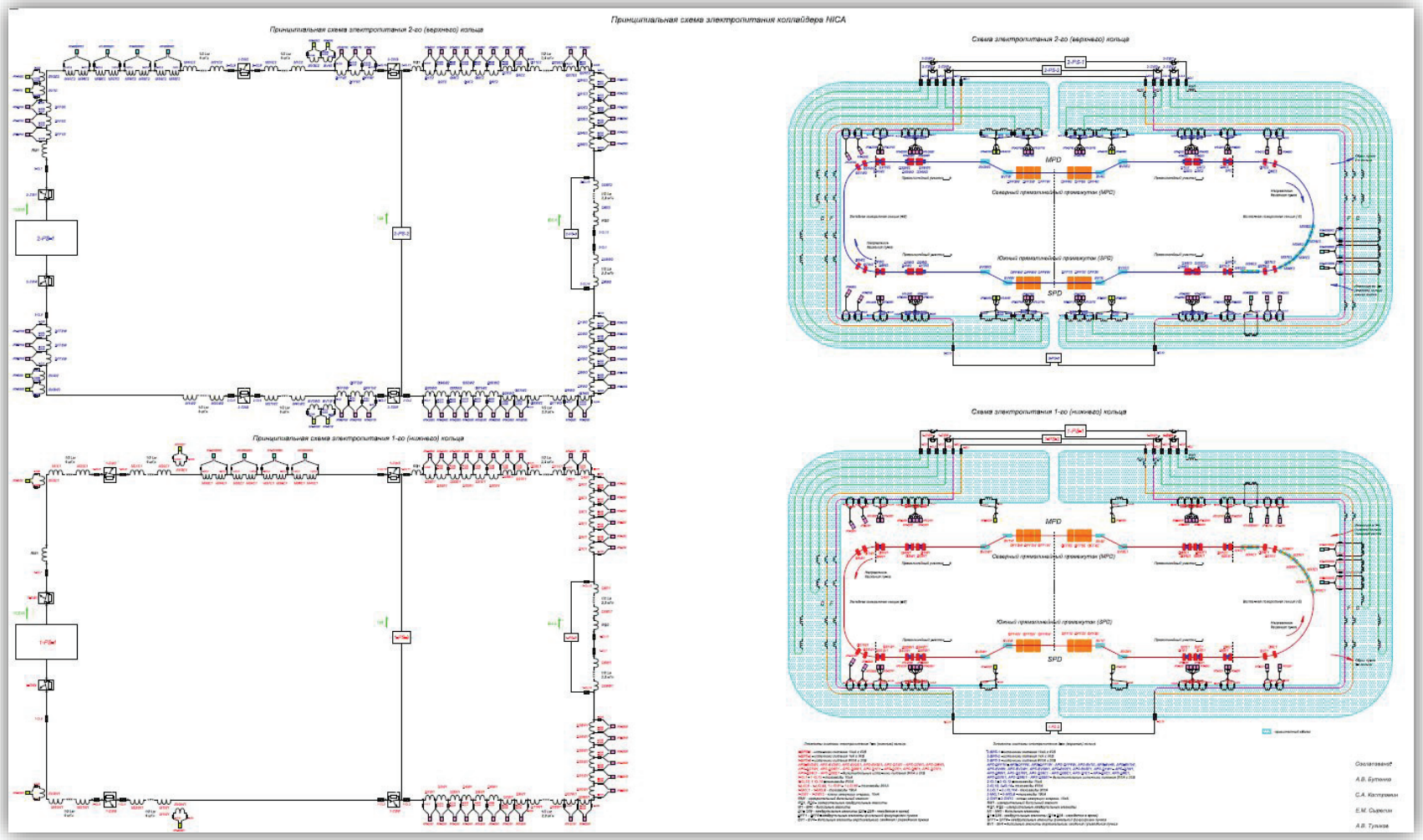
Energy evacuation switch

production

40

The power supply system of the Collider

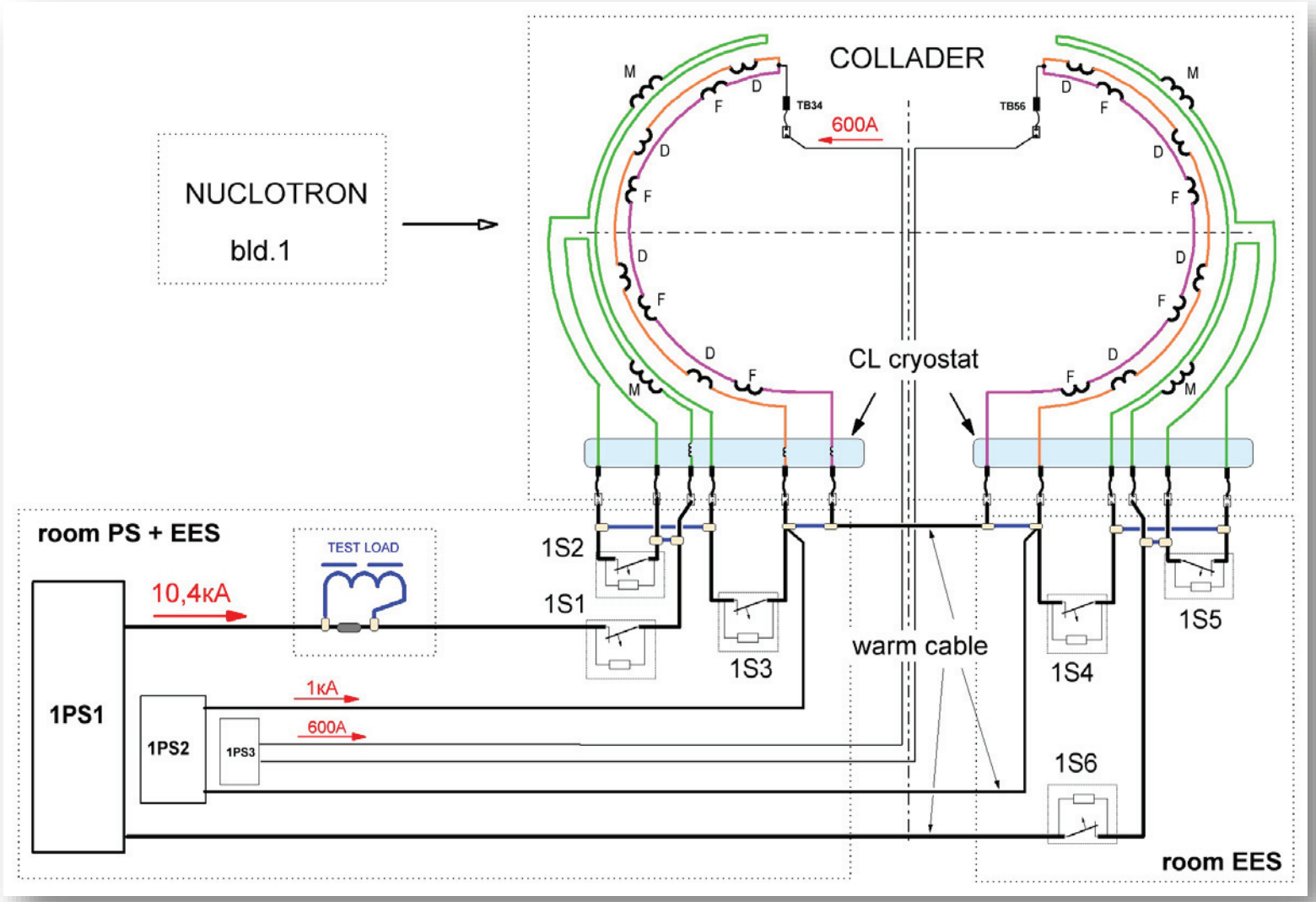
Full schematic diagram of the power supply



. + additional sources (10V x 300A) - 88 pcs.

41

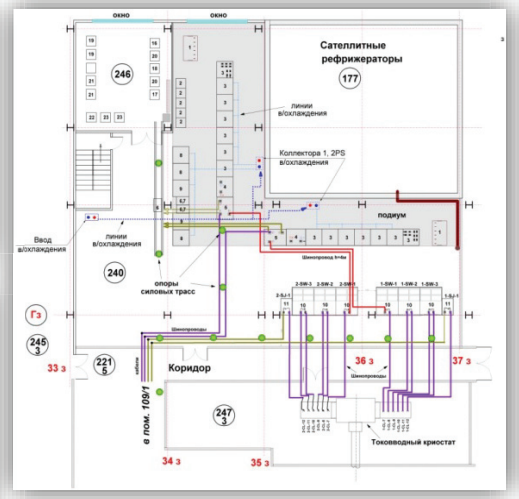
Fundamentally wiring diagram power circuit

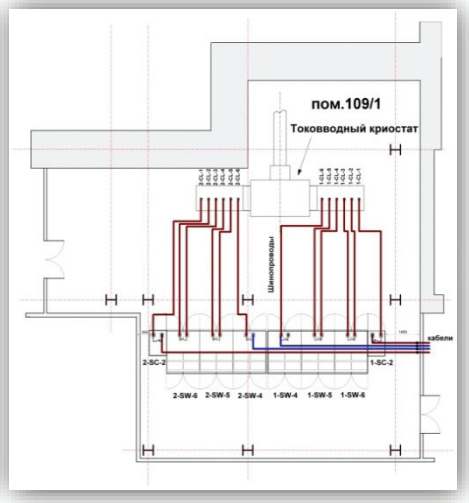


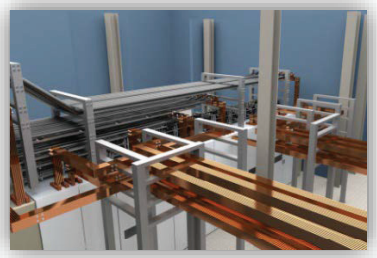
42

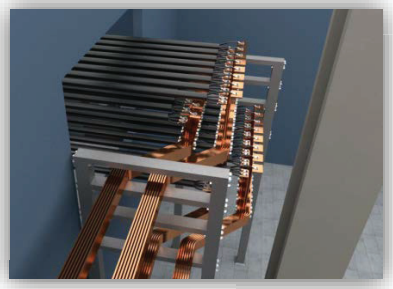
Fundamentally wiring diagram power circuit

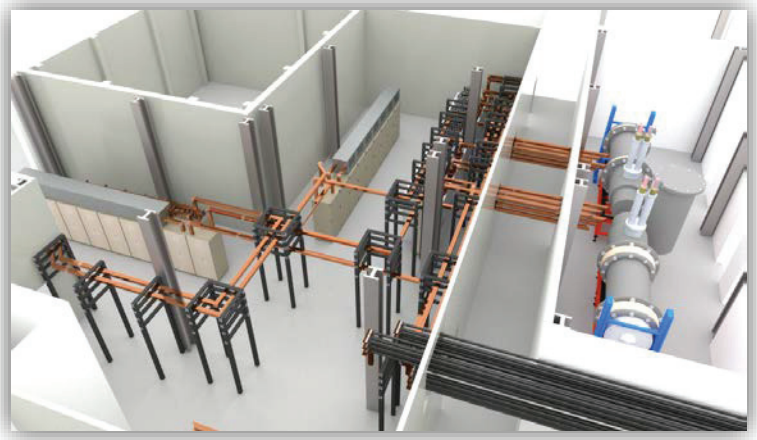
Equipment placement plan. Development of a 3d model of the equipment layout







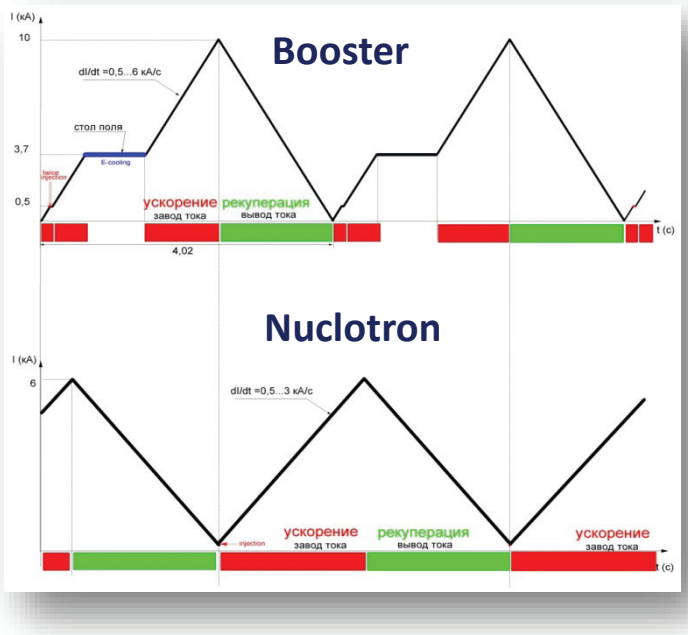




Development of Booster and Nuclotron power supply systems

General accelerator NICA power supply system

Current cycles of the NICA



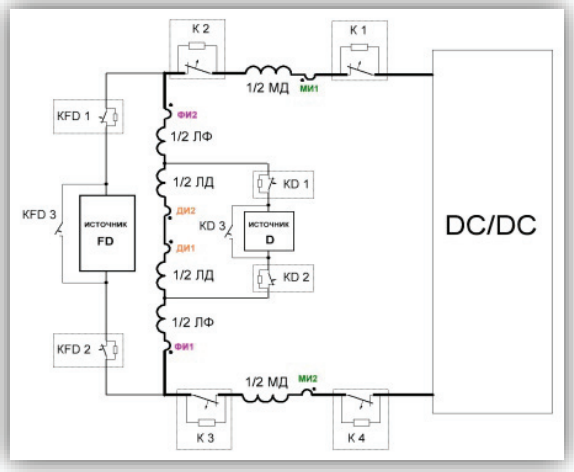
booster and the Nuclotronin the collider injection chain

The main parameters of the magnetic cycles of the Booster and the Nuclotron

Parameters	Booster	Nuclotron
Total inductance of superconducting magnets, L [мН]	**31**	**120**
Maximum current (field),[A] ([T])	**10 (1,8)**	**6,0 (2,0)**
Voltage of current sources,[V]	**260**	**450**
Accumulated for each half-cycle (current rises) energy,[MJ]	**1,6**	**2,16**
Peak power of the current source, [MW]	**2,2**	**2,7**

Development of Booster and Nuclotron power supply systems

Scheme Booster

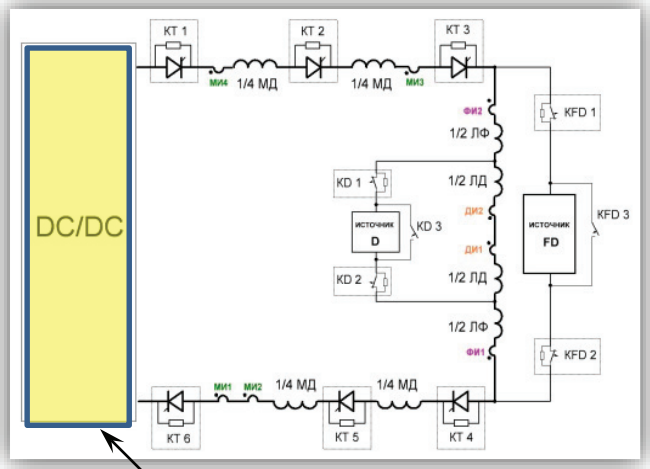


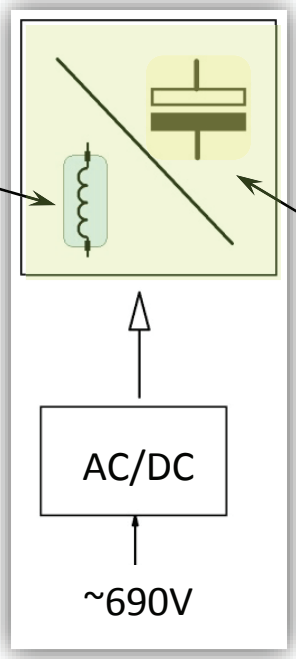
existing PS

W booster 1,6MJ

W nuclotron 2,2MJ

Scheme Nuclotron





storage energy

New power supply:
- current – 6kA
- voltage – 450V
- ΔI – 50ppm

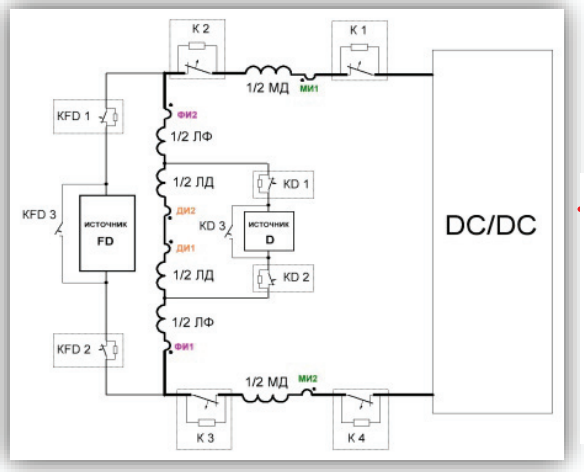
Capacitor bank
-capacitor capacity 60F
- voltage 400V
- energy 4.8MJ

Superconducting magnetic energy storage – SMES

- solenoid made of high temperature superconducting cable,
- energy 3-5 MJ,
- temperature 28 K,
- liquid neon cooling,
- operating current up to 10 kA,
- 3x inductively coupled windings.

Development of Booster and Nuclotron power supply systems

Scheme Booster



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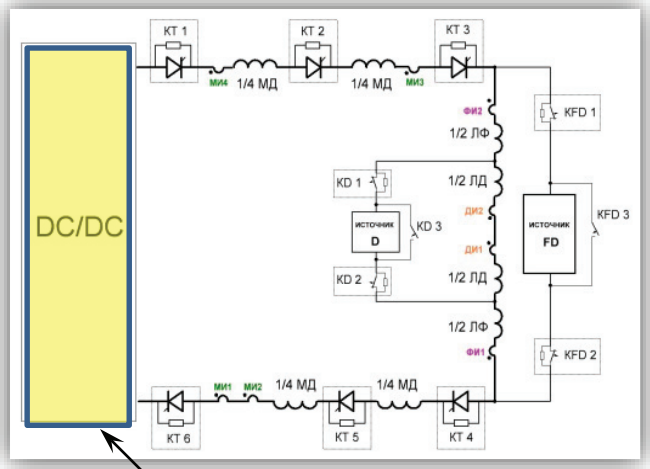

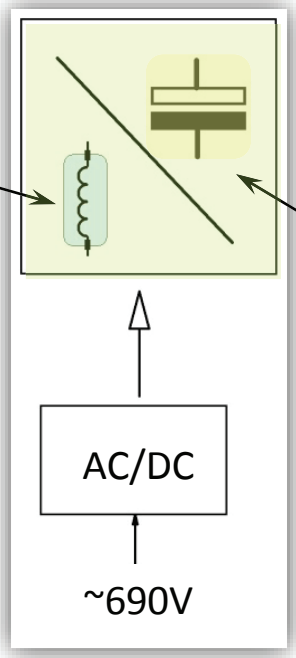

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Thank you for your attention!