The Sirius Power Supplies Reliability Scenario

Power Converters Group – CoP

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MINISTRY OF SCIENCE TECHNOLOGY AND INNOVATION

BRAZILIAN GOVERNMENT BRASIL UNITING AND REBUILDING

Summary

- 1. CNPEM and DAT
- 2. Sirius Overview
- 3. Power Supply System Reliability
- 4. In-house PSs
- 5. Off-the-shelf PSs
- 6. Conclusion

Summary

The Power Converters Group - CoP

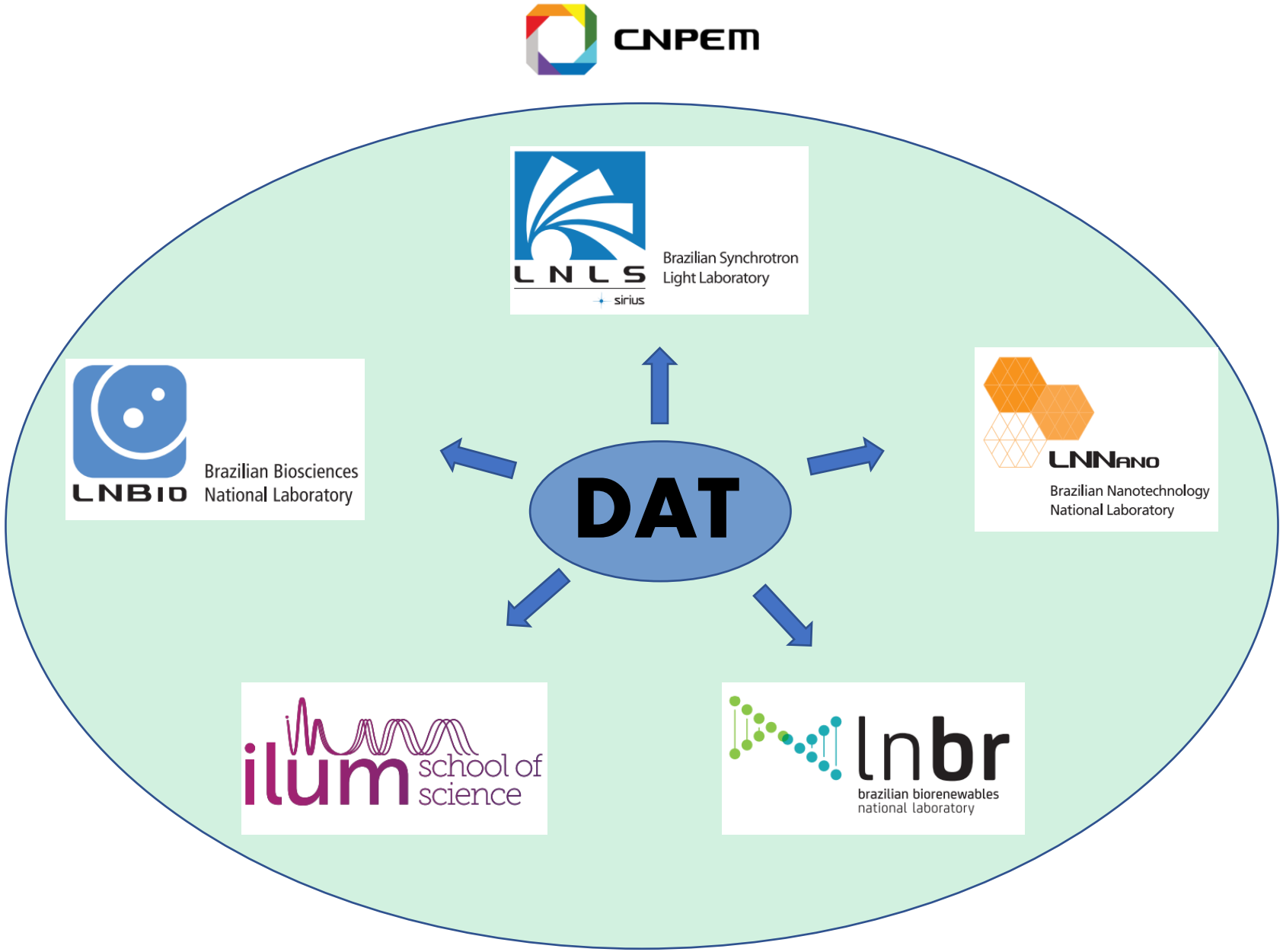
Group Leader
- Bruno Edson Limeira

Engineers
- Felipe Santiago P de Oliveira
- William Contesini
- Leandro de Oliveira Porto

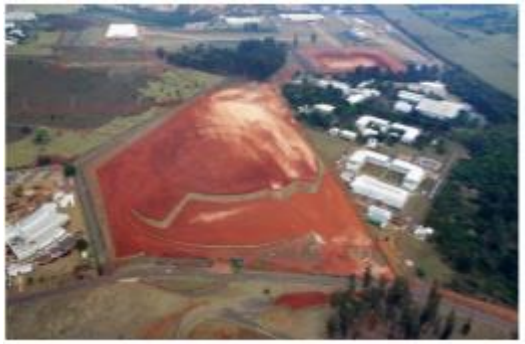
Technicians
- Gustavo Machado Rogatto
- Gustavo Rodrigues de Oliveira
- Gabriel Fernandes dos Santos

Trainee
- Lucas Carnevalli de Almeida

1. CNPEM and DAT

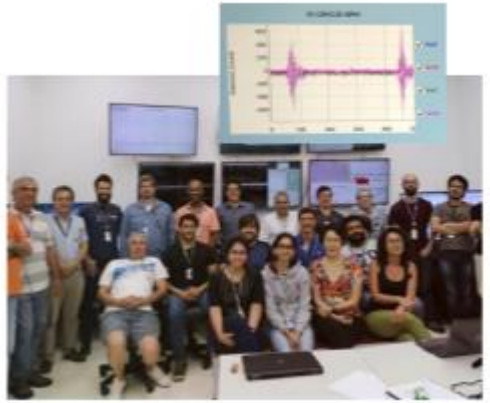


Summary

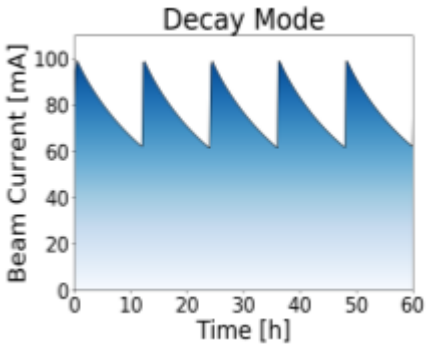


Oct 14, 2014
Land ready

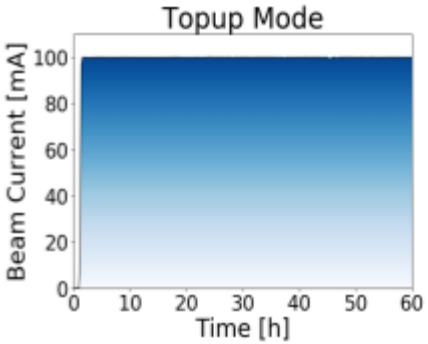
Oct 2018
Building ready



Nov 22, 2019
1st turn in SR



Nov 1, 2021
100 mA, decay



Mar 2023
100 mA, **top-up**
regular user's runs

2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023

covid

May 2018
Linac installed

Sep 2019
SR assembled
& in vacuum

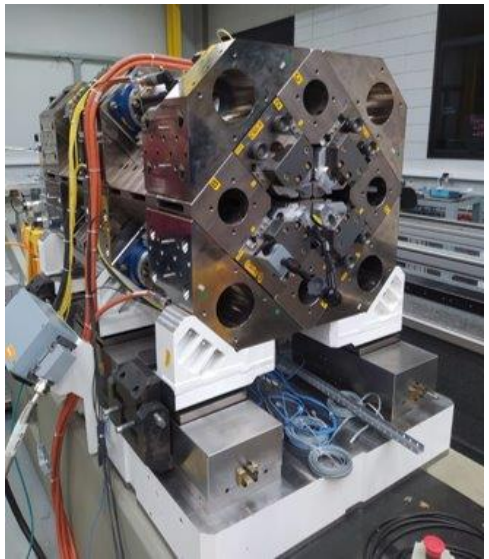
Dec 14, 2019
1st stored beam

Jul 2020
1st experiments

Nov 2022
1st regular user's call
and
Start of FOFB
operation

Parameter	Today	Phase 1 (end of 2024)
Beam energy	3.0 GeV	3.0 GeV
Current	100 mA	350 mA
Injection mode	top-up	top-up
Beam stability	~ 1% σ_x ~ 4% σ_y	< 10% σ
Beamlines (in oper.)	6	14

Critical systems	Today	Phase 1
RF cavities	• 1 NC Petra7 cell	• 2 SC CESR type • 3HC (1.5 GHz)
RF power	• 120 kW SSA	• 480 kW SSA
FOFB	• rate = 48 kHz • crossover = 400 Hz	• rate = 96 kHz • crossover = 1 kHz
Insertion Devices	• Commissioning APUs • IDs from old SR (UVX) - EPU - Wiggler	• APUs • In-vacuum • Vertical polarization • Delta (in-house) • Apple-II



Delta Undulator

2. Sirius Overview

SIRIUS - 2023 SCHEDULE

versão 30/03/2023

January 2023

Sun	Mon	Tue	Wed	Thu	Fri	Sat
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

February 2023

Sun	Mon	Tue	Wed	Thu	Fri	Sat
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28				

March 2023

Sun	Mon	Tue	Wed	Thu	Fri	Sat
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

April 2023

Sun	Mon	Tue	Wed	Thu	Fri	Sat
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30						

May 2023

Sun	Mon	Tue	Wed	Thu	Fri	Sat
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

June 2023

Sun	Mon	Tue	Wed	Thu	Fri	Sat
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	

July 2023

Sun	Mon	Tue	Wed	Thu	Fri	Sat
						1
2	3	4	5	6	7	8
9	10	11	ER2LS 12	13	14	15
16	17	18	ER2LS 19	20	21	22
23	24	25	26	27	28	29
30	31					

August 2023

Sun	Mon	Tue	Wed	Thu	Fri	Sat
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

September 2023

Sun	Mon	Tue	Wed	Thu	Fri	Sat
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

October 2023

Sun	Mon	Tue	Wed	Thu	Fri	Sat
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

November 2023

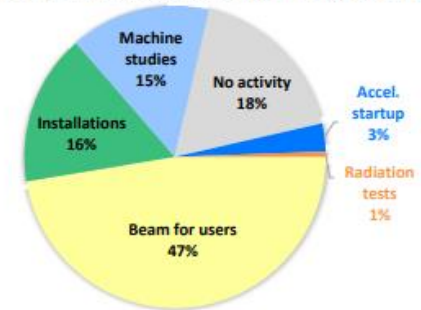
Sun	Mon	Tue	Wed	Thu	Fri	Sat
			1	2	3	4
5	6	7	RAU 8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

December 2023

Sun	Mon	Tue	Wed	Thu	Fri	Sat
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

Beam for Beamlines	Machine Study	Acelerator Startup	Installation. Tunnel open	RAD tests Tunnel closed	Unattended. Tunnel closed
77 dias 21.1 %	55 dias 15.1 %	11 dias 3.0 %	59 dias 16.2 %	2 dias 0.5 %	65 dias 17.8 %
					365 dias 100.0 %

SIRIUS - DISTRIBUTION OF SHIFT HOURS IN 2023



Shift hours	2023	2022
Beam for users	4152	3360
Installations	1416	1968
Machine studies	1320	1296
No activity	1560	1608
Accel. startup	264	480
Radiation tests	48	48

Summary

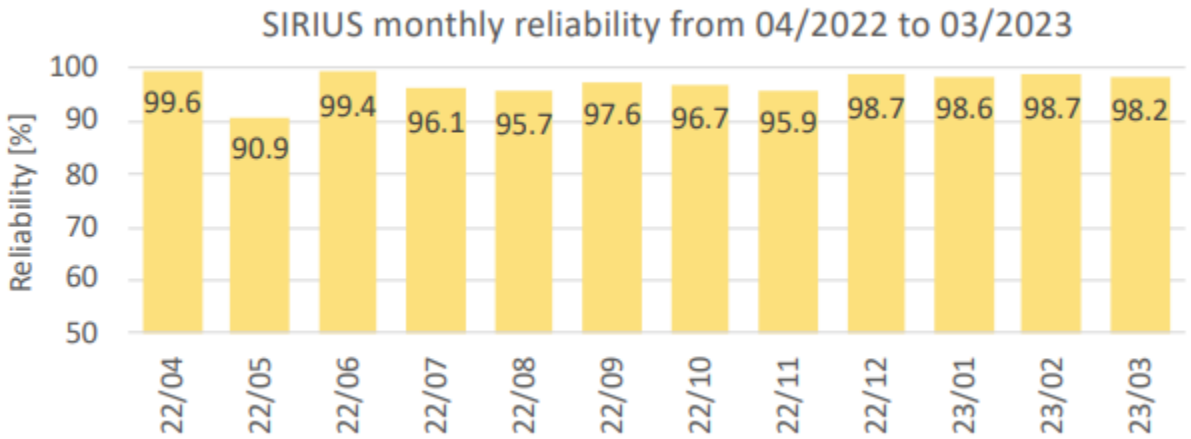
Sirius uses Olog as maintenance management tool, but not optimized for it!

↳ **Very hard to create accurate maintenance statistics!**

It is been studied to start using Jira Service.

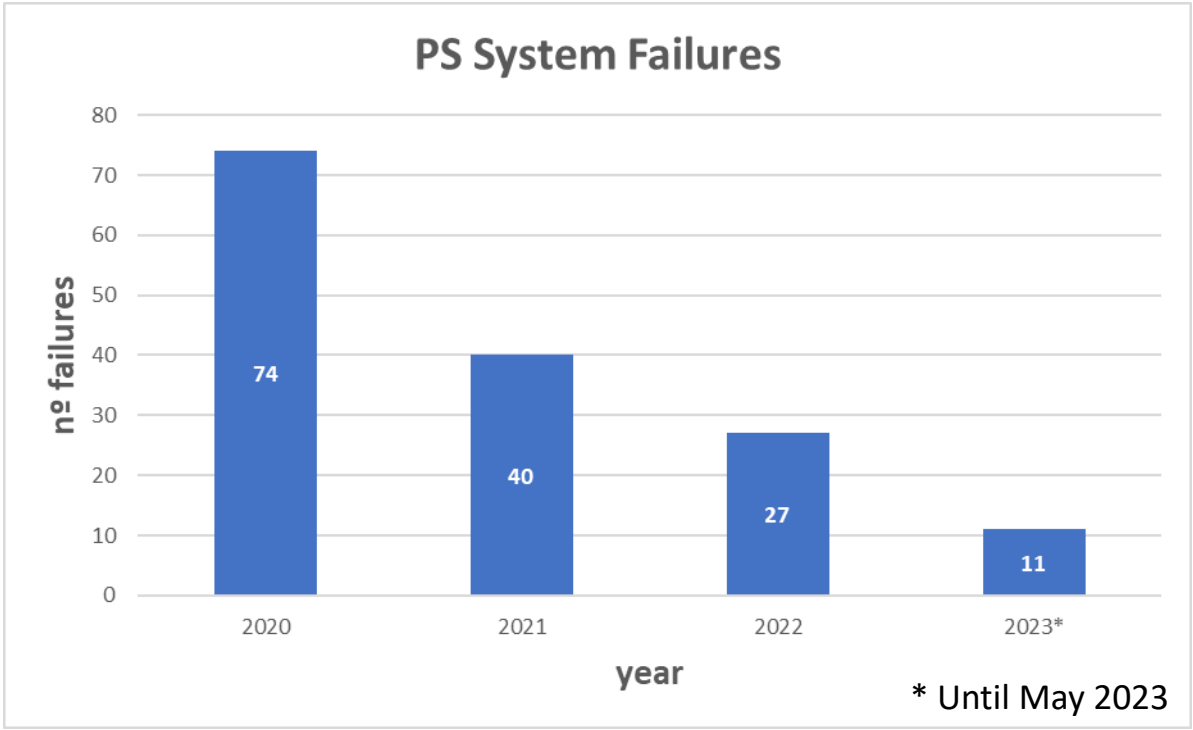
Jira Service Management

3. Power Supply System Reliability



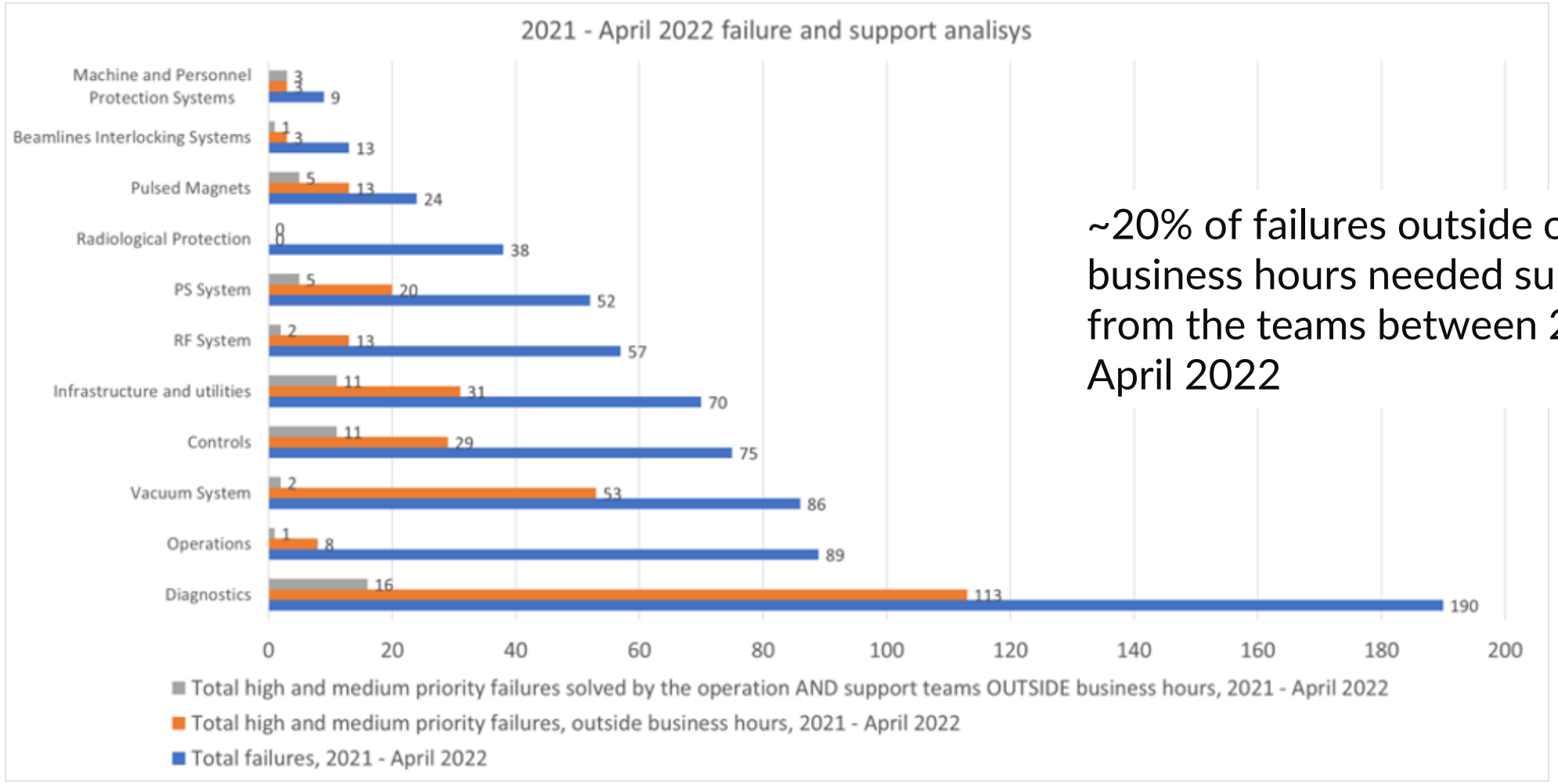
→ Overall Reliability of 97,4%

- ~750 Low Power PS (FBP)
- 45 High Power PS – 54 modules
- 6 AC High Power PS
  - 21 Output Stages
  - 18 Input Stages
  - 18 Rectfiers
- 40 Regatron PS for FAP DC-Link
- ~200 TDK Lambda PS - SSA for RF system and DC-Links
- 23 BPM Power Supplies (Acopian)
- 16 Ion Pump PS for LINAC (Shanghai Sanjing)
- 48 Power Supplies for LINAC (SINAP)
- 20 PS for FOFB (8 channels each) – Not maintained by CoP



* Until May 2023

3. Power Supply System Reliability



~20% of failures outside of business hours needed support from the teams between 2021 and April 2022

Summary

We have three families of In-house Power Supplies:

- Low Power PS (FBP)
  - 10 A/10 V
  - Bipolar (4Q)
  - Uses Off-the-shelf PS as DC-Link
- High Power PS (FAP)
  - Up to 800 A and 800 V
  - Modular - 225 A/400 V per module
  - Monopolar (1Q)
  - Used only in Storage Ring
  - Uses Off-the-shelf PS as DC-Link
- AC High Power PS (FAC)
  - Up to peak 1000 A and 800 V
  - Modular – 550 A/250V per module
  - Bipolar (4Q)
  - Used only in Booster
  - All in-house developed

https://accelconf.web.cern.ch/ipac2019/papers/tupmp001.pdf

https://accelconf.web.cern.ch/ipac2019/papers/tupmp002.pdf

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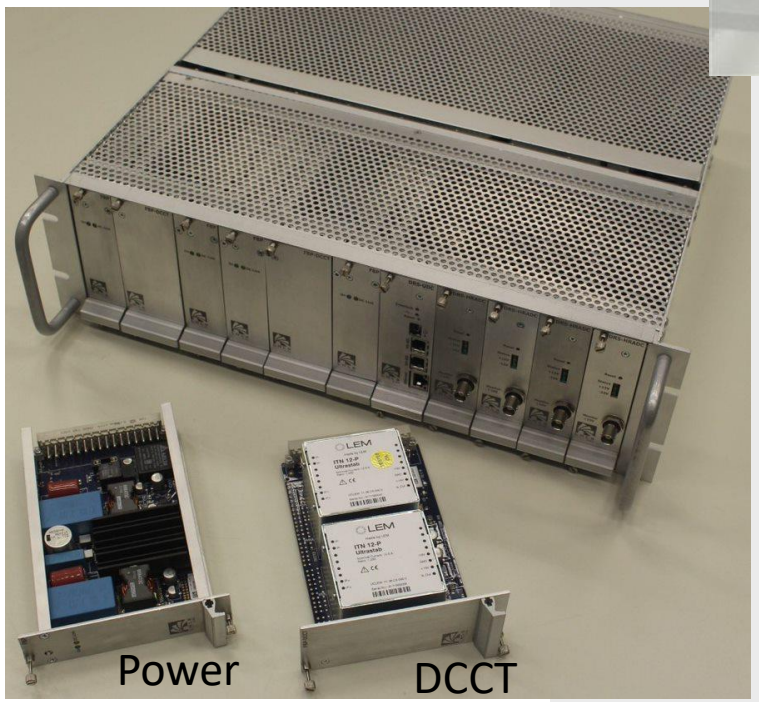
DC-Link
TDK Lambda HWS1500



Power Module

DCCT

We have three families of In-house Power Supplies:

- Low Power PS (FBP)
  - 10 A/10 V
  - Bipolar (4Q)
  - Uses Off-the-shelf PS as DC-Link
- High Power PS (FAP)
  - Up to 800 A and 800 V
  - Modular - 225 A/400 V per module
  - Monopolar (1Q)
  - Used in Storage Ring and Transport Lines
  - Uses Off-the-shelf PS as DC-Link
- AC High Power PS (FAC)
  - Up to peak 1000 A and 800 V
  - Modular – 550 A/250V per module
  - Bipolar (4Q)
  - Used only in Booster
  - All in-house developed

DC-Link
Regatron TopCon Quadro

Power Module

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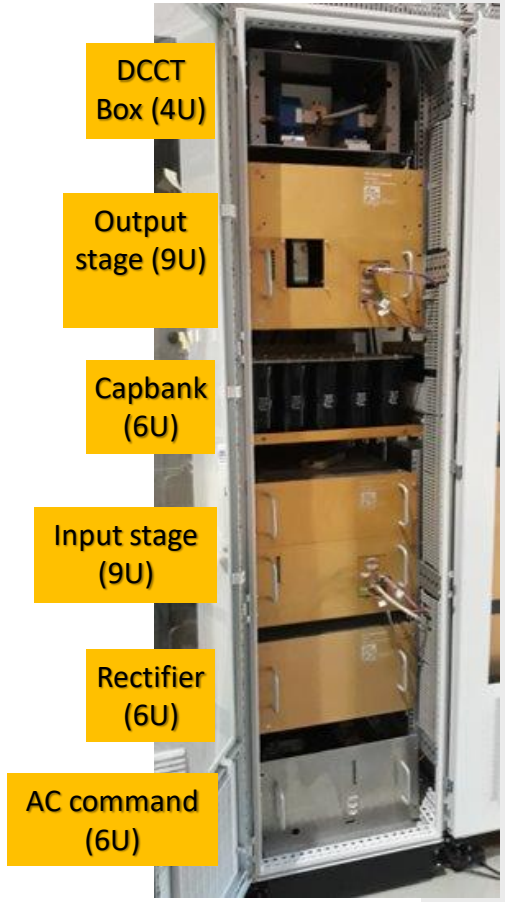
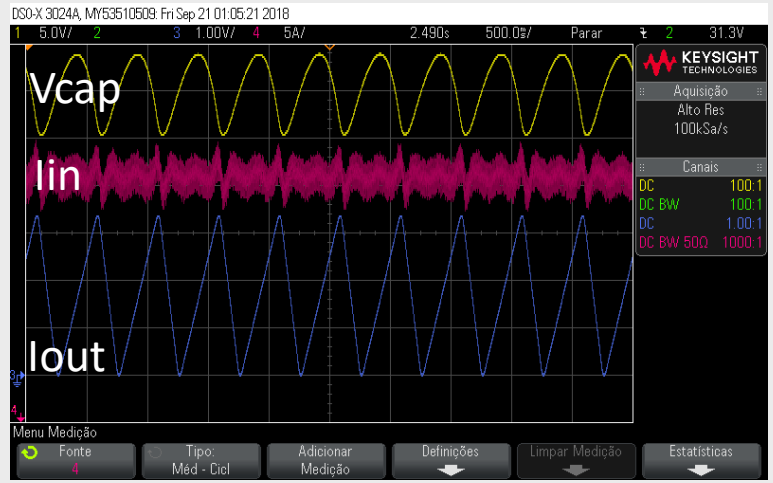
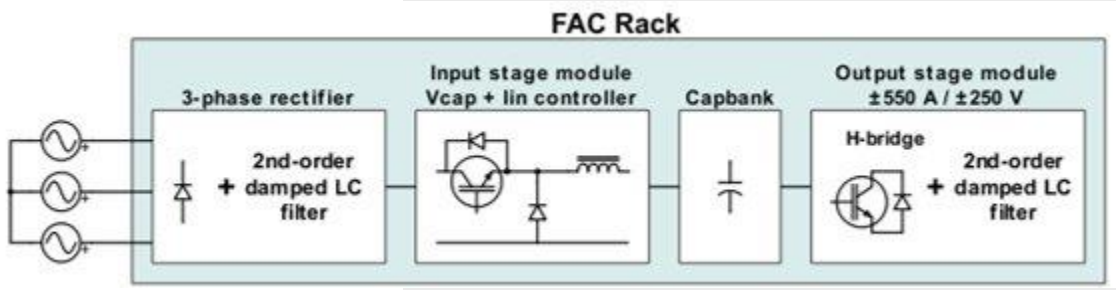
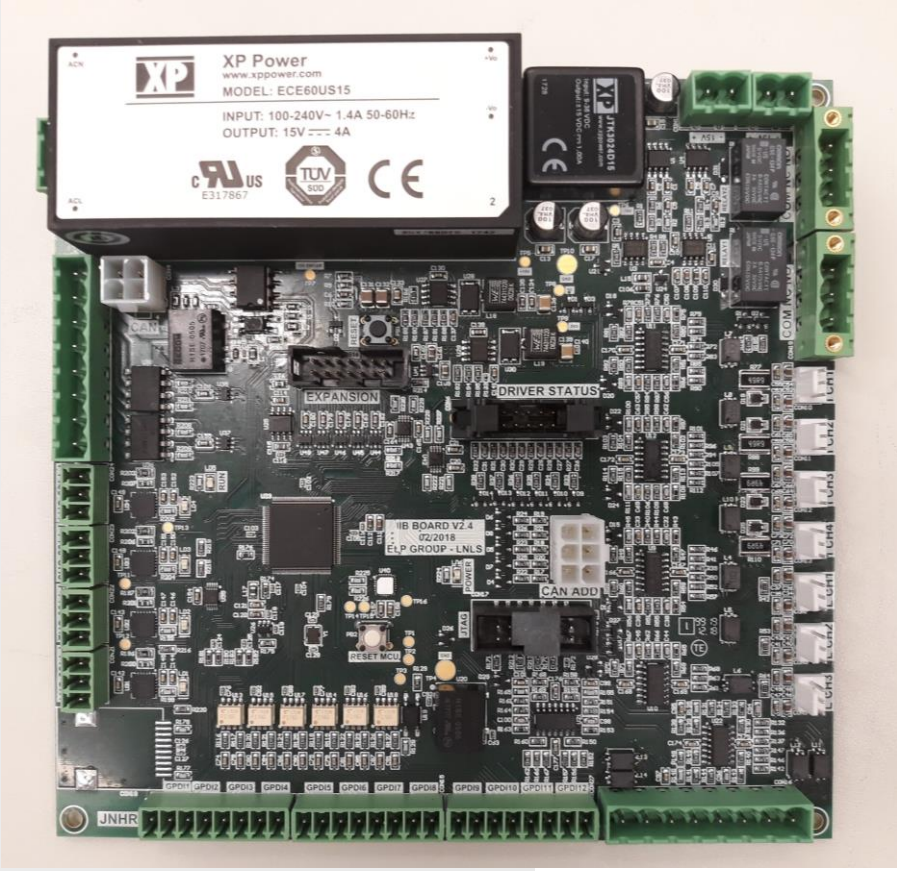
- Low Power PS (FBP)
  - 10 A/10 V
  - Bipolar (4Q)
  - Uses Off-the-shelf PS as DC-Link
- High Power PS (FAP)
  - Up to 800 A and 800 V
  - Modular - 225 A/400 V per module
  - Monopolar (1Q)
  - Used only in Storage Ring
  - Uses Off-the-shelf PS as DC-Link
- AC High Power PS (FAC)
  - Up to peak of 1000 A and 800 V
  - Modular – 550 A/250V per module
  - Bipolar (4Q)
  - Used only in Booster
  - All in-house developed







Internal Interlock Board



- In-house development
- 2 channels of +15 V for driver supply;
- 4 channels of isolated current measurement input;
- 3 channels of isolated voltage measurement input;
- 12 General Purpose Digital Output;
- 4 General Purpose Digital Input;
- 4 PT100 inputs;
- 4 non-insulated voltage measurement input;
- CAN communication;

Failures:

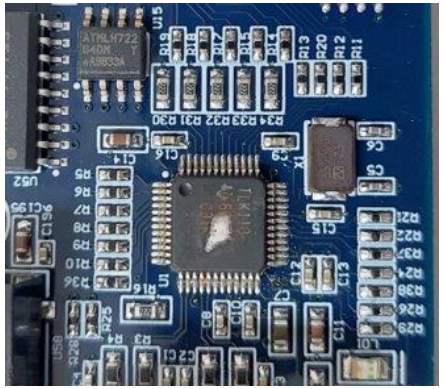
- ↳ Problem with CAN communication due to poor implementation (solved in 2021)
- ↳ Inverted cables in the CAN cable
- ↳ Problems with PT100 measurement in some modules (EMI issues)
- ↳ Problems with JTAG cables (EMI issues)

Digital Regulation System (DRS)

- In-house development
- Used in every in every in-house developed PS
- 18 bits resolution
- Up to 4 High Resolution ADC
- Up to 16 PWMs (optical fiber)
- RS-485 and CAN communication

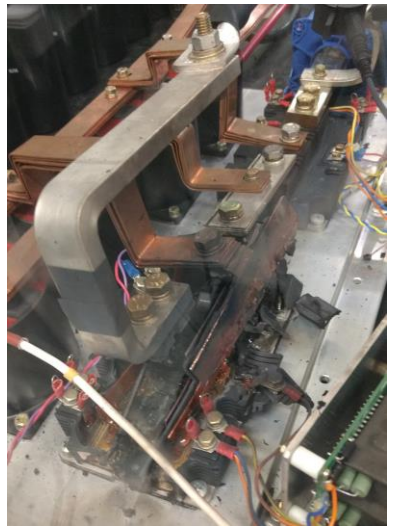
Failures:

↳ Fault in the Ethernet IC -> Necessary to remove the IC from 326 boards!



Capacitor Bank

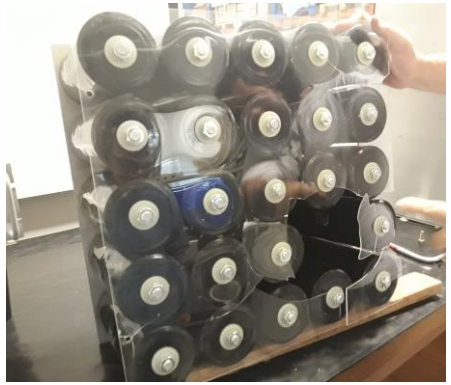
- 3 different models
  - 1.3 F/ 305 V – 25 capacitors of 52 mF/305 V in parallel (Felsic Capax 761438)
  - 725 mF/ 400 V – 25 capacitors of 29 mF/ 400V in parallel (Kendeil K11S)
  - 1.18 F / 100 V – 25 capacitors of 47 mF / 100V in parallel (EPCOS B41456)
- Have a fuse connected in series for protection

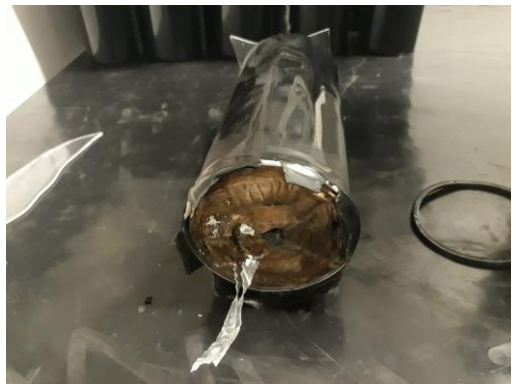


Failures:

↳ Capacitor explosion – due to dust between the copper plates (hypothesis...)

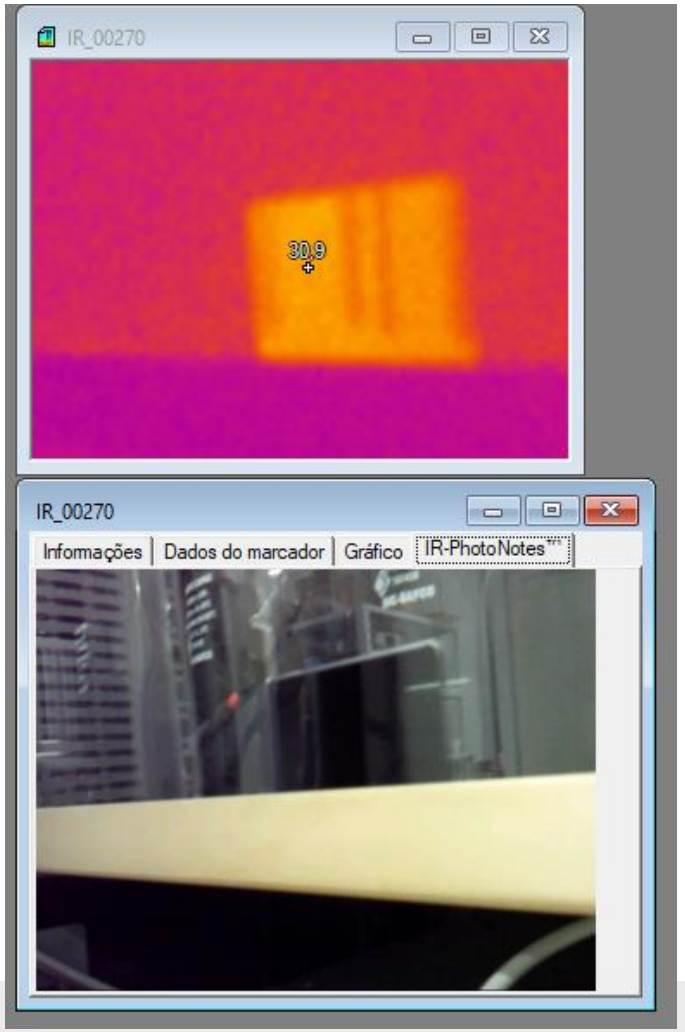
↳ We've added polycarbonate protection in these capacitor banks





Capacitor Bank

- With top-up operation, the Booster PS are now operating all the time, hence the capacitor are in a more demanding scenario
- We are testing the possibility to let the PS ramping only during injections (every 3 min)
- We still don’t have estimative of the lifetime of the capacitors
- We still don’t have thought about the logistic of spare parts storage.



Summary

TDK Lambda

~200 units in operation

0 failures until now!

RF Solid State Amplifier

5. Off-the-shelf PS

Regatron

Used as DC-Link for Storage Ring PSs

4 different models
- 100 V
- 130 V
- 200V
- 400V

Magnet PS	400 V - 100 A Model	200 V - 200 A Model	130 V - 308 A Model	100 V - 400 A Model
Dipoles		PA-RaPSD01:PS-DCLink-1A		
		PA-RaPSD01:PS-DCLink-1B		
		PA-RaPSD01:PS-DCLink-3A		
		PA-RaPSD01:PS-DCLink-3B		
		PA-RaPSD03:PS-DCLink-2A		
		PA-RaPSD03:PS-DCLink-2B		
		PA-RaPSD03:PS-DCLink-4A		
		PA-RaPSD03:PS-DCLink-4B		
		PA-RaPSD05:PS-DCLink-1A		
		PA-RaPSD05:PS-DCLink-1B		
		PA-RaPSD05:PS-DCLink-3A		
		PA-RaPSD05:PS-DCLink-3B		
		PA-RaPSD07:PS-DCLink-2A		
		PA-RaPSD07:PS-DCLink-2B		
		PA-RaPSD07:PS-DCLink-4A		
		PA-RaPSD07:PS-DCLink-4B		
Quadrupoles		PA-RaPSA01:PS-DCLink-QFAP		
	PA-RaPSA01:PS-DCLink-QFB			
				PA-RaPSA03:PS-DCLink-QDAP
		PA-RaPSA04:PS-DCLink-QDB		
			PA-RaPSA06:PS-DCLink-Q13A	
			PA-RaPSA06:PS-DCLink-Q13B	
			PA-RaPSA06:PS-DCLink-Q13C	
			PA-RaPSA07:PS-DCLink-Q24A	
			PA-RaPSA07:PS-DCLink-Q24B	
			PA-RaPSA07:PS-DCLink-Q24C	
Sextupoles			PA-RaPSB01:PS-DCLink-SDAP0	
		PA-RaPSB01:PS-DCLink-SDB0		
			PA-RaPSB03:PS-DCLink-SFAP0	
		PA-RaPSB03:PS-DCLink-SFB0		
			PA-RaPSB04:PS-DCLink-SDA12	
		PA-RaPSB04:PS-DCLink-SDB1		
			PA-RaPSB05:PS-DCLink-SDA3SFA1	
		PA-RaPSB05:PS-DCLink-SDB2		
			PA-RaPSB07:PS-DCLink-SFA2SDP1	
		PA-RaPSB07:PS-DCLink-SDB3		
			PA-RaPSB08:PS-DCLink-SDP23	
		PA-RaPSB08:PS-DCLink-SFB1		
			PA-RaPSB10:PS-DCLink-SFP12	
		PA-RaPSB10:PS-DCLink-SFB2		
Quantity	**1**	**25**	**13**	**1**

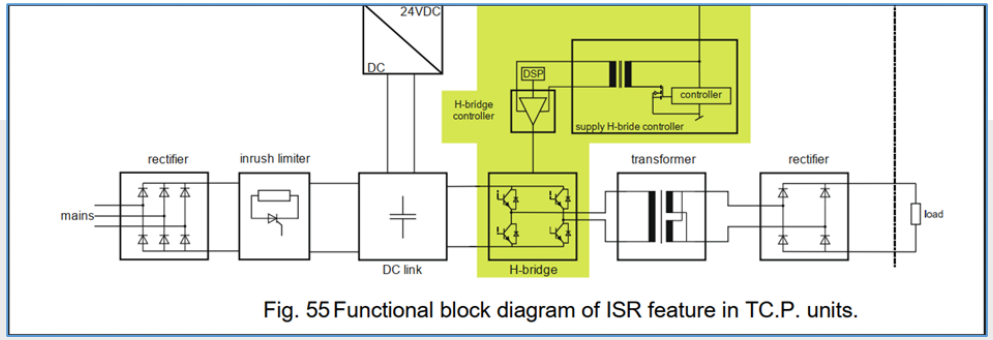


Fig. 55 Functional block diagram of ISR feature in TC.P. units.

MINISTRY OF SCIENCE TECHNOLOGY AND INNOVATION

BRAZILIAN GOVERNMENT
BRASIL
UNITING AND REBUILDING

Regatron

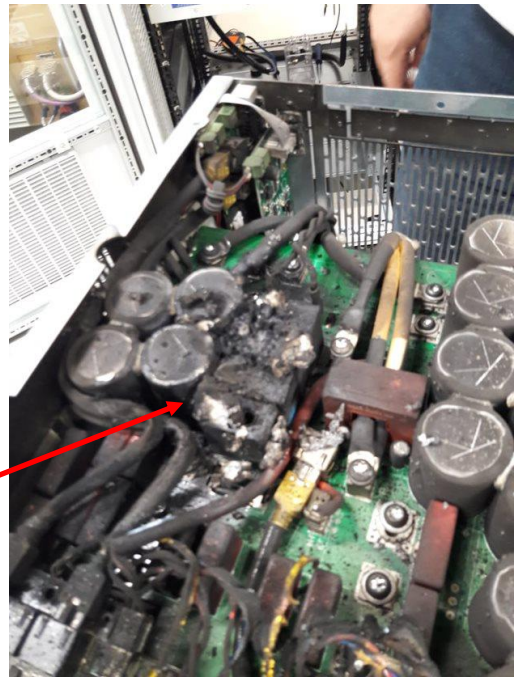
Used as DC-Link for Storage Ring PSs

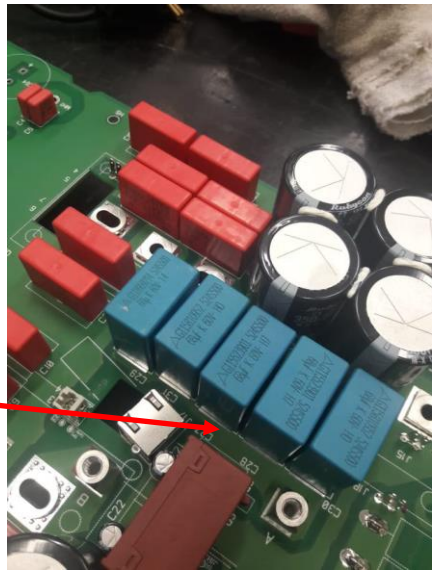
4 different models

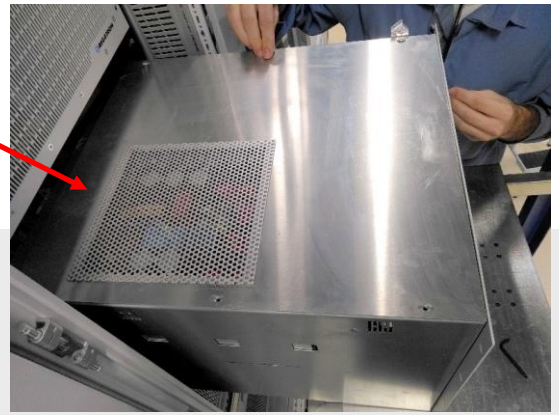
- 100 V
- 130 V
- 200V
- 400V

Damage in some capacitors:

- Recurrent event that happened in the Storage Ring Dipole PS
- Some of the capacitor were badly damaged due to overtemperature
- Regatron did not solved the problem
- The problem was solved by adding one other capacitor in parallel (we suggested it and bought the capacitors…) and adding drills in the cover
- Since them, the PS room is operating with ~18ºC ambient temperature







Regatron

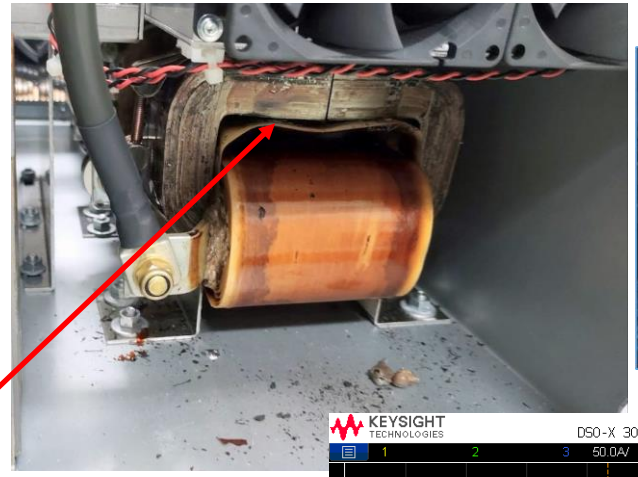
Used as DC-Link for Storage Ring PSs

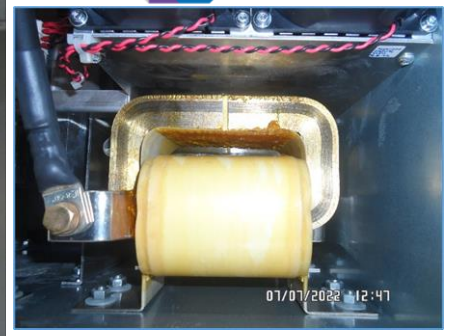
4 different models

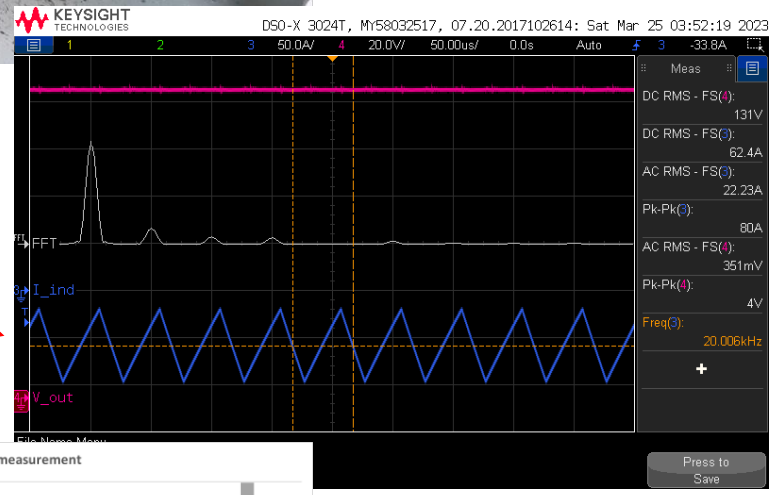
- 100 V
- 130 V
- 200V
- 400V

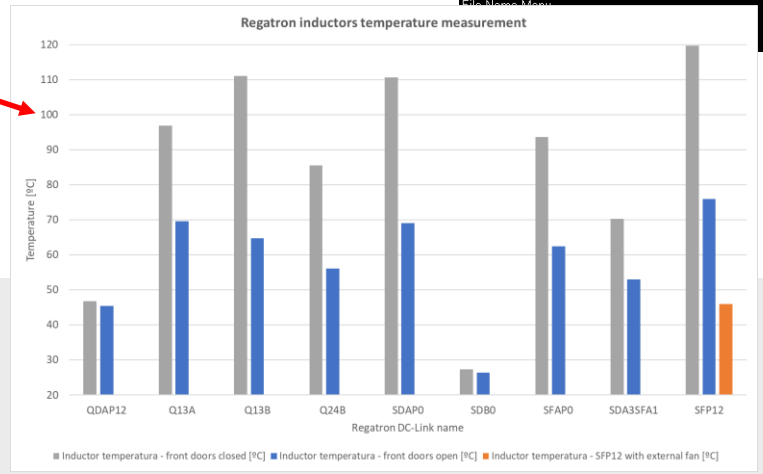
Overtemperature in the output inductors:

- The inductors heat to the point that the gap of the core melts
- The inductor uses silicon steel sheets for its core (not ferrite)
- We measured a ripple of 80 Appk at switching frequency (20 kHz)
- Regatron says the problem is the refrigeration of our racks
- We've measured the temperature in the inductors of some PSs in operation (worst cases)
- We've measured in one PS outside of the rack and the core reached ~70ºC





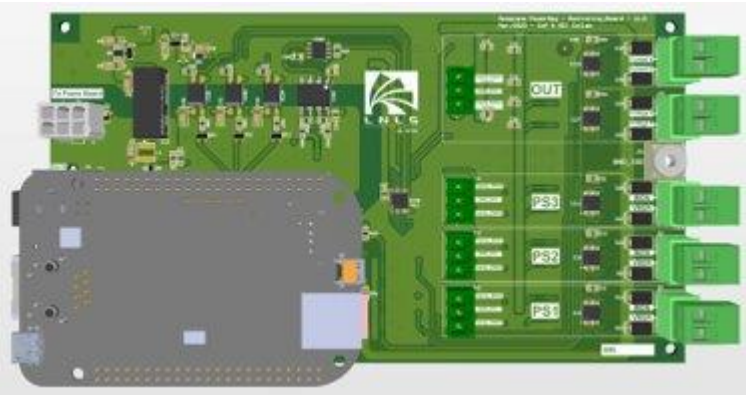




Acopian

PS for the BPMs racks

- One PS has 3 power modules in parallel
- Redundant (should be…)
- Recurrent problem of current distribution between modules
- Don’t have remote monitoring
- One unit was the cause of **108 failures** in one BPM rack in one week!
- Acopian said the problem was calibration, but it wasn’t
- Several project errors found in the PS:
  - Low impedance connected in the voltage and current measurement channels.
  - Reference connections not done properly
  - Control of the output voltage done via feedback measurement
  - Some resistor from the display voltage divider resistors shorted by tracks in the PCB
- The problems are been solved (by us) and remote monitoring board is been developed



Summary

- 1. CNPEM and DAT
- 2. Sirius Overview
- 3. Power Supply System Reliability
- 4. In-house PSs
- 5. Off-the-shelf PSs
- 6. Conclusion

6. Conclusion

- It is a problem not to have a good maintenance management tool from the beginning
- Our PS system is showing good reliability
- We should have paid more attention on off-the-shelf equipment tests
- Maintenance of off-the-shelf equipment is not easy (black-box)
- It would be better to use PLC for the internal interlock system
- We plan enhancing and expanding the maintenance teams for Sirius (not only for power supplies)

Thank you

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