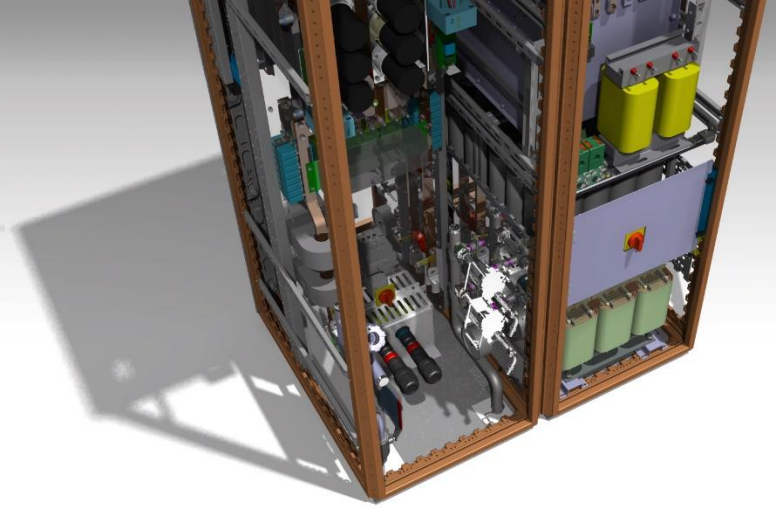


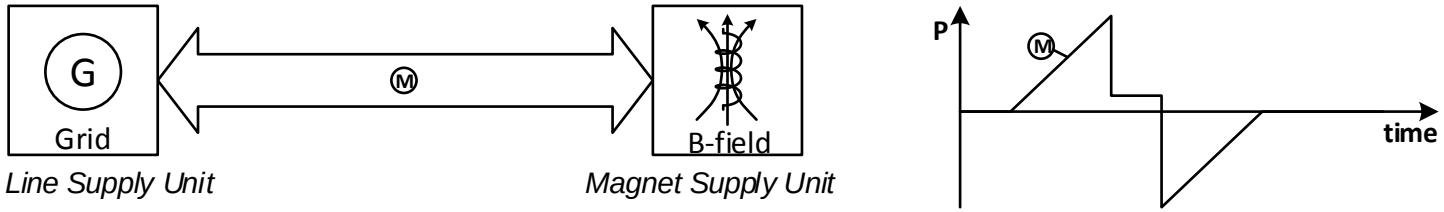
SIRIUS converter family

CERN-TE-EPC
13 June 2017

Overview

- **Introduction to Sirius Family**
  - Target applications
  - Choosing the right model
- **Design industrialisation**
  - Production file
  - Testing aids
- **ALBA pre-study**
  - Bending magnets
  - Quadrupole magnets
  - Budget allocation

Introduction to Sirius



Magnet type	Total (1.2sec)	Recoverable	Thermal loss (1.2sec)
Quadrupole (26Gev)	11kJ	6kJ	5kJ
Small Dipole (26Gev)	31.5kJ	25kJ	6.5kJ
Large Dipole (26Gev)	101kJ	82kJ	19kJ

Annual cost of electricity of each 1kJ of losses: 242 CHF*

(Non-recoverable/consumed every 1.2seconds)

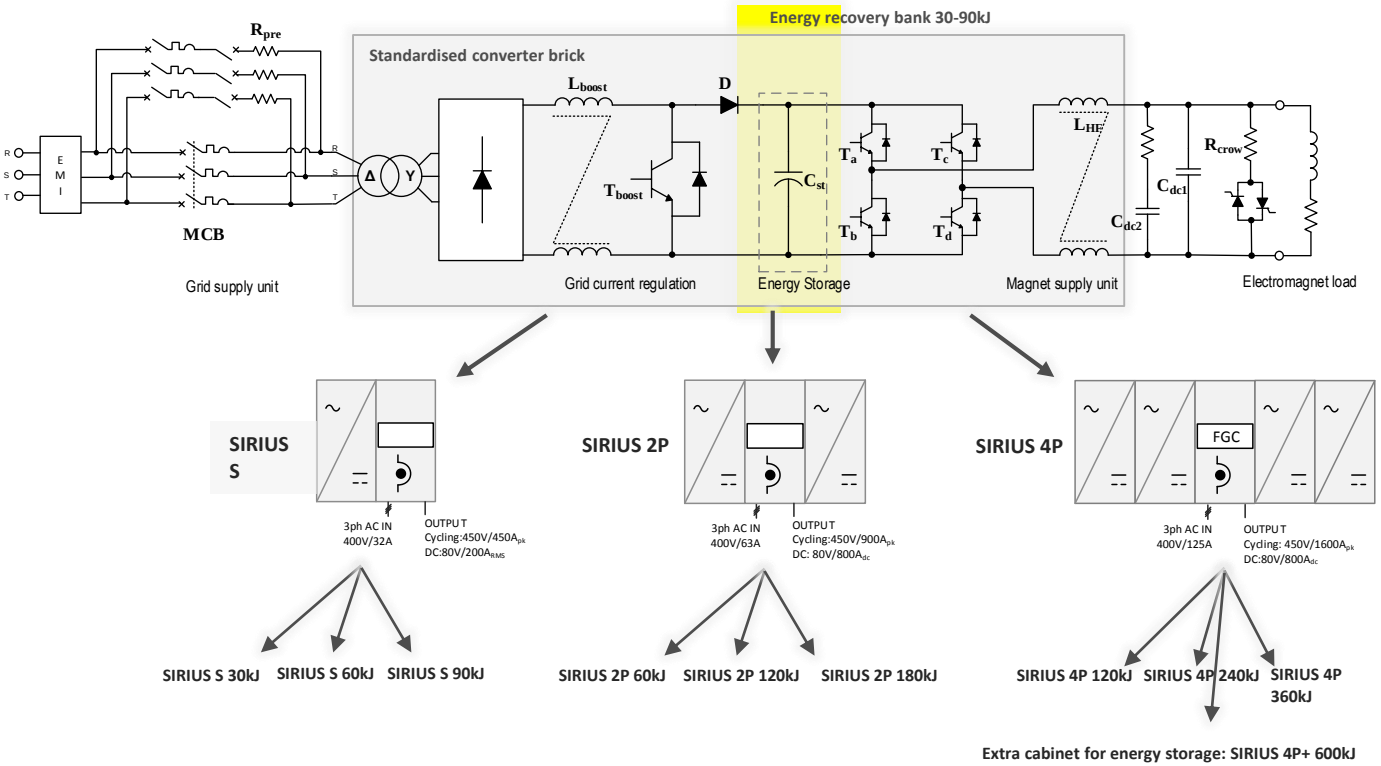
Sirius is primarily suitable for:

- ***Cycling applications with considerable amounts of recoverable energy***
- ***RMS loss minimisation and magnet field conditioning (with FGC3)***
- ***Long life and fast cycling***

* Assuming cost of electricity of 0.045 CHF/kWh. 1kJ of energy over a 1.2sec cycle corresponds to 1kJ/1.2sec=0.83kW of average power. Assuming this 1.2sec (PS) cycle repeats for 24hours over 270 working days the total energy required from the power network (for each 1kJ) is 5378kWh/annum. If this energy is not recovered in capacitor banks after every magnet cycle it is returned to the power network and is not remunerated by the provider.

Power Converter for Transfer lines

Family	Type	Configuration	Grid Supply (RMS values)	Output	
				Continuous RMS	Cycling peak
SIRIUS	**S**	Single module	400V/32A	±80V/±200A	±450V/±450A
SIRIUS	**2P**	2 modules in parallel	400V/63A	±80V/±400A	±450V/±900A
SIRIUS	**4P**	4 modules in parallel	400V/125A	±80V/±800A_{RMS}	±450V/±1600A



Power Converter for Transfer lines

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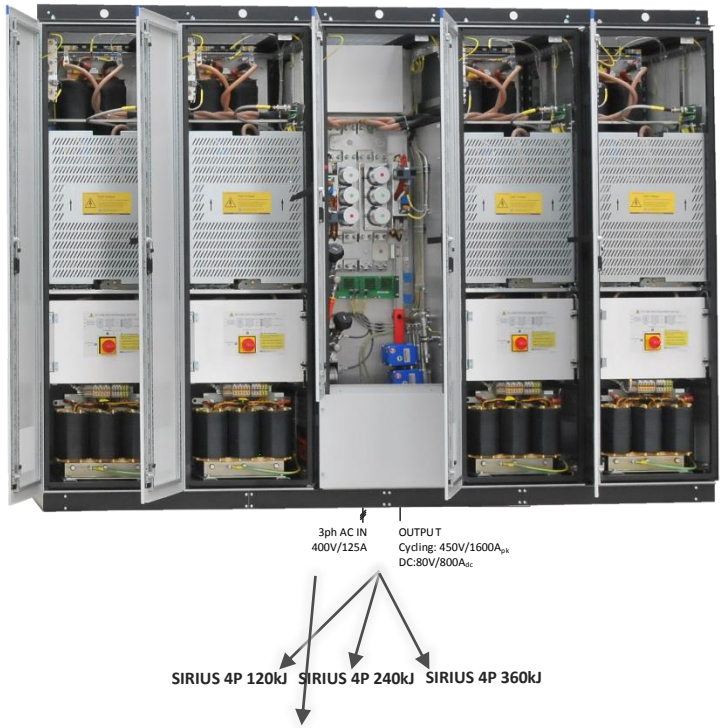
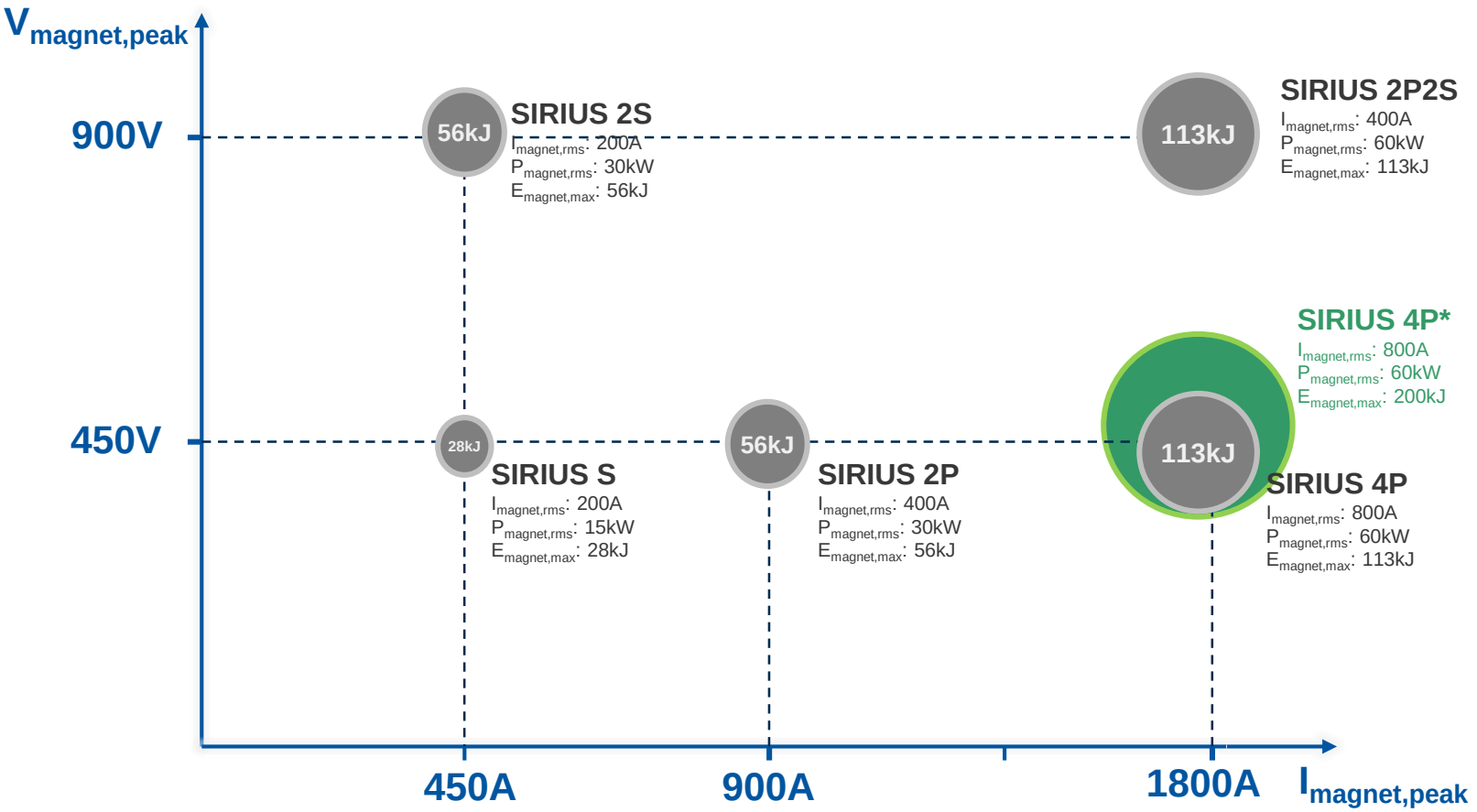
SIRIUS	**4P**	4 modules in parallel	400V/125A	±80V/±800A_{RMS}	±450V/±1600A



Power Converter for Transfer Lines



NOTE! Sirius a Fast Pulsed converter range exists too!

Choosing the right model

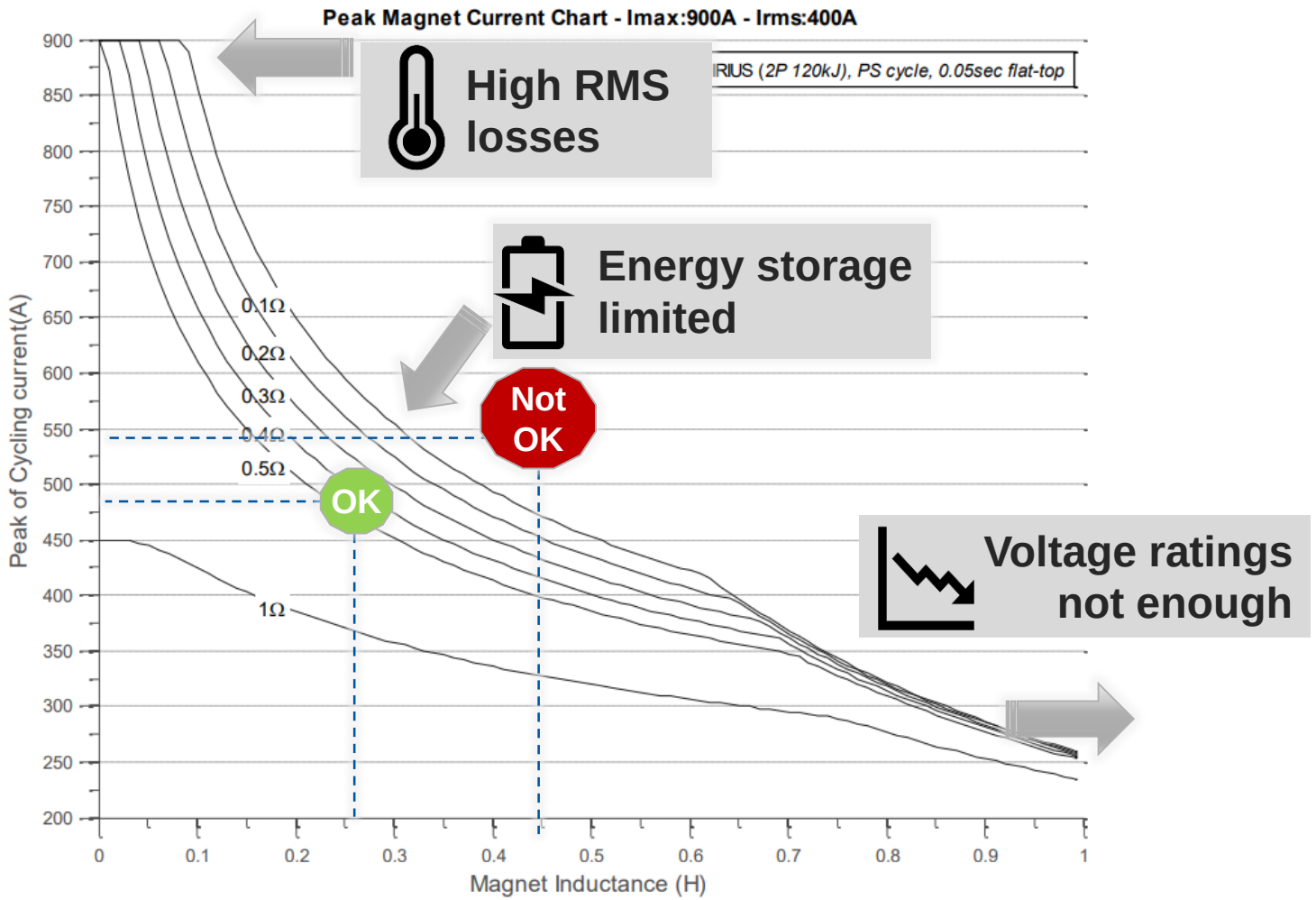
	Sirius S	Sirius 2P	Sirius 4P
Output power limited by the front-end Boost stage power rating	15kW	30kW	60kW
Recoverable magnet energy is limited by the built-in capacitive storage[1] (0 to 7 banks per power brick[2])	77kJ	144kJ	288kJ
Output RMS current is limited by the output H-bridge stage ratings and lifetime[3] considerations	200A 450A peak	400A 900A peak	800A 1800A peak

[1] moderate dc-link discharge depth of 300V

[2] capacitor banks 4 to 7 require additional rack

[3] assuming 200million cycles with 1.2second period

Choosing the right model

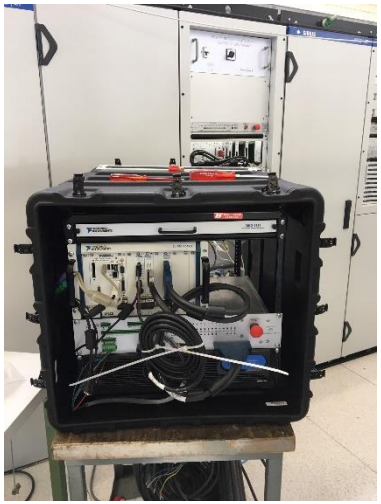


Selection curves:https://edms.cern.ch/document/1540790/1

Design Industrialisation

Design industrialisation

- The main principles:
  - **Standardise solution across different projects**
    - Produce in large scale -> lower prices
  - **Create a complete production file**
    - No development effort for supplier -> wide range of bidders
  - **Cern supply of critical components (to maintain the know-how)**
    - DCCTs, power stacks where made by specialist companies -> reduce risks
  - **Use off-the-shelf parts where possible**
    - Energy storing capacitors
    - Metal cabinets
    - All switchgear
- Test tools made for industry and troubleshooting



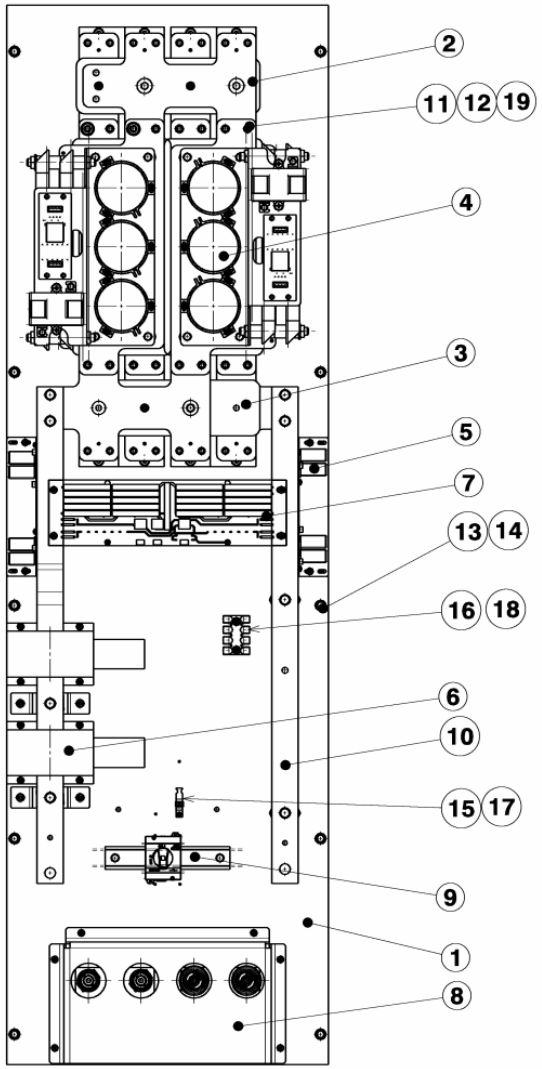
Production file

Production file contents:

- Electronic Schematics (1 per model)
- Mechanical drawings (~130 drawings)
- Bill of materials (electromechanical)
- List of cables
- Suppliers list (suggestions)

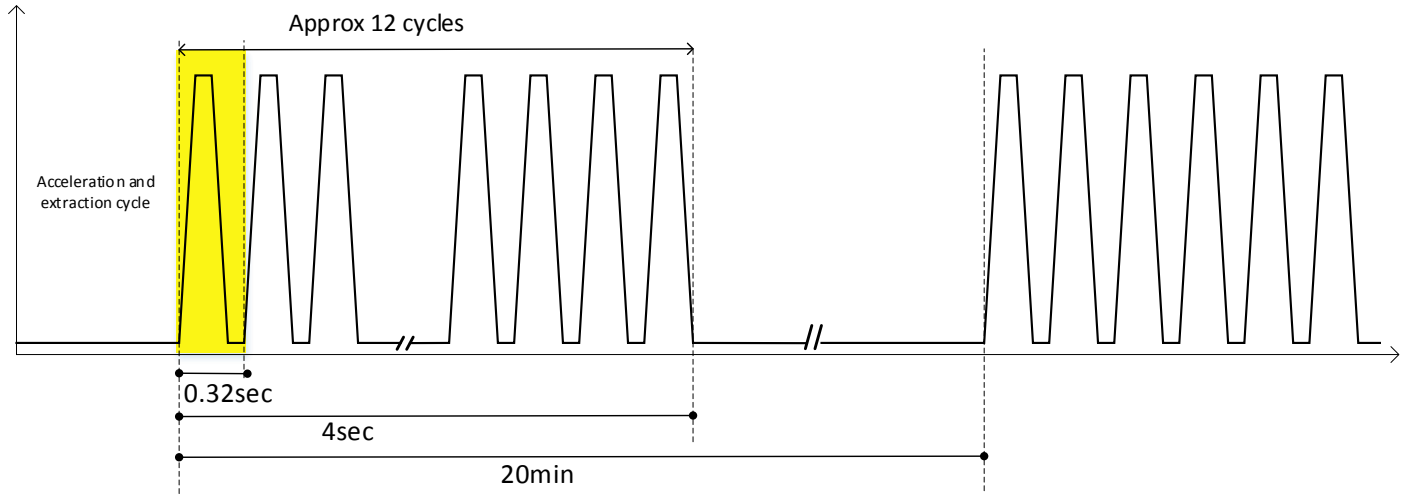
Items specified/tendered for by CERN:

- magnetic materials
- power stack
- DCCT
- RegFGC3 chassis and cards



The ALBA pre-study

User requirements

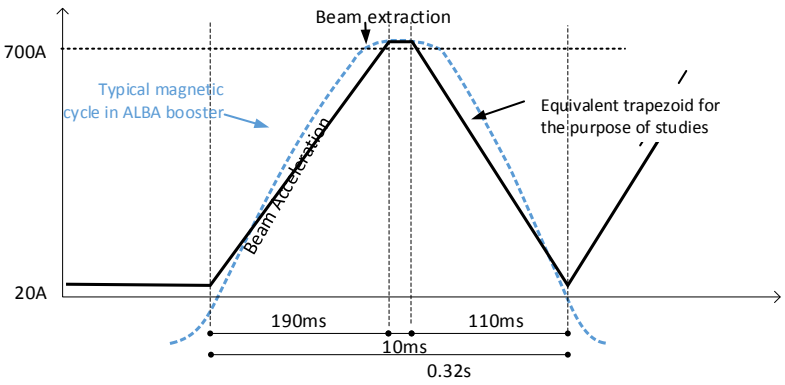


Bending magnets

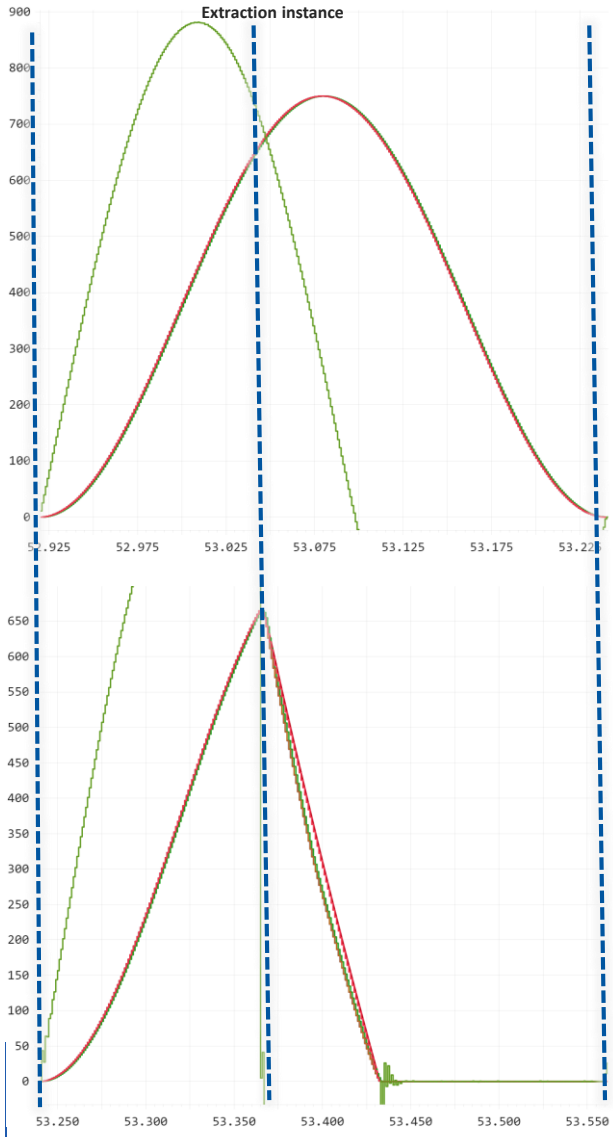
Quantity	Value	Unit	notes
APPLICATION DERIVED PARAMETERS			
L_{MAGNET}	0.1	H	
R_{MAGNET}	0.355	0.355	Includes 20mOhm cabling
$I_{MAGNET,sat}$	?	A	
Imin	20	A	
Imax	700	A	Converter rating: 900A
Vmax	500	V	Converter rating :900V
Energy to recover	25	kJ	1 cap bank per brick
Rise time (Tr)	0.19	Sec	
Fall time (Tf)	0.11	Sec	
Flat-top duration (Tft)	0.01	Sec	
Period time	0.32	Sec	
Current RMS 4s	410	A	See note 1
Current RMS 40s	39	A	
Current DC max	400	A	See note 2
Power Peak	350	kW	
Power 4s	59.7	kW	Converter rating: 60kW
Operating time	5700	h/annum	
Cycles	17100	Cyc/annum	See note 3
Cycles in lifetime	342000	Cycles	In 20 years
CONVERTER PARAMETERS			
Solution	2x SIRIUS 2P2S Input: 3ph, 400V, 125A, cosφ:0.93, THD:30% Output: $900V_{PK}$,$900A_{PK}$, $400A_{RMS}$, $60kW_{RMS,}$ $E_{Recoverable}$:132kJ)		

Simplified (trapezoid) cycle

- Fast ramping with 500V



Bending magnets



Sinusoidal cycle

- Irms=459A
- P=74.8kW (over 0.320s)

Semi-sinusoidal cycle

- Irms =282A
- P=52.6kW (over 0.320s)

Booster Quadrupole magnets

Quantity	Value	Unit	notes
APPLICATION DERIVED PARAMETERS			
L_{MAGNET}	0.0272	H	8 magnets in series
R_{MAGNET}	0.44	Ohm	*discrepancy with spec
$I_{MAGNET,sat}$	?	A	
Imin	0	A	
Imax	180	A	Converter rating: 450A
Vmax	81	V	Converter rating: 450V
Energy to recover	0.4	kJ	
Rise time (Tr)	0.24	Sec	
Fall time (Tf)	0.04	Sec	
Flat-top duration (Tft)	0.01	Sec	
Period time	0.32	Sec	
Current RMS 4s	102	A	Converter rating: 200A
Current RMS 40s	10	A	
Current DC max	185	A	Converter rating: 200A
Power Peak	14.6	kW	
Power 4s	4.6	kW	
Operating time	5700	H	
Cycles	17100	Cycles/annum	
Cycles in lifetime	342000	Cycles	In 20 years
CONVERTER PARAMETERS			
Solution	SIRIUS S Input: 3ph, 400V, 32A, cosφ:0.93, THD:30% Output: $450V_{PK}$,$450A_{PK}$, $200A_{RMS}$, $15kW_{RMS,}$ $E_{Recoverable}$:33kJ)		

Booster QS340

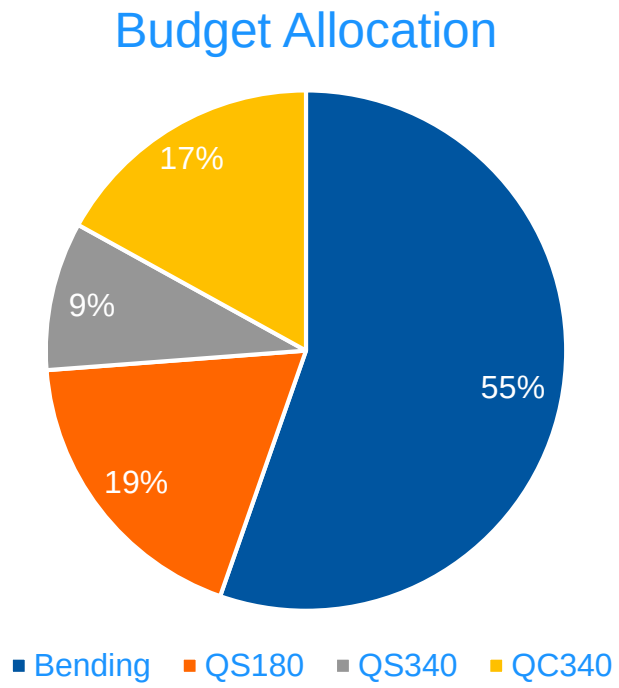
Quantity	Value	Unit	notes
APPLICATION DERIVED PARAMETERS			
L_{MAGNET}	0.048	H	8 magnets in series
R_{MAGNET}	0.61	Ohm	*discrepancy with spec
$I_{MAGNET,sat}$	?	A	
Imin	0	A	
Imax	180	A	Converter rating: 450A
Vmax	115	V	Converter rating: 450V
Energy to recover	0.8	kJ	
Rise time (Tr)	0.24	Sec	
Fall time (Tf)	0.05	Sec	
Flat-top duration (Tft)	0.01	Sec	
Period time	0.32	Sec	
Current RMS 4s	105	A	Converter rating: 200A
Current RMS 40s	10	A	
Current DC max	157	A	Converter rating: 200A
Power Peak	20.7	kW	
Power 4s	6.7	kW	
Operating time	5700	H	
Cycles	17100	Cycles/annum	
Cycles in lifetime	342000	Cycles	In 20 years
CONVERTER PARAMETERS			
Solution	SIRIUS S Input: 3ph, 400V, 32A, cosφ:0.93, THD:30% Output: $450V_{PK}$,$450A_{PK}$, $200A_{RMS}$, $15kW_{RMS,}$ $E_{Recoverable}$:33kJ)		

Booster QC340

Quantity	Value	Unit	notes
APPLICATION DERIVED PARAMETERS			
L_{MAGNET}	0.216	H	8 magnets in series
R_{MAGNET}	2.36	Ohm	*discrepancy with spec
$I_{MAGNET,sat}$	?	A	
Imin	0	A	
Imax	180	A	Converter rating: 450A
Vmax	460	V	Converter rating: 450V
Energy to recover	3.5	kJ	
Rise time (Tr)	0.24	Sec	
Fall time (Tf)	0.06	Sec	
Flat-top duration (Tft)	0.01	Sec	
Period time	0.32	Sec	
Current RMS 4s	105	A	Converter rating: 200A
Current RMS 40s	10	A	-
Current DC max	113	A	Converter rating: 200A
Power Peak	82.8	kW	
Power 4s	25.9	kW	
Operating time	5700	H	
Cycles	17100	Cycles/annum	
Cycles in lifetime	342000	Cycles	In 20 years
CONVERTER PARAMETERS			
Solution	SIRIUS 2S Input: 3ph, 400V, 63A, cosφ:0.93, THD:30% Output: $900V_{PK}$,$450A_{PK}$, $200A_{RMS}$, $30kW_{RMS,}$ $E_{Recoverable}$:66kJ)		

Budget allocation

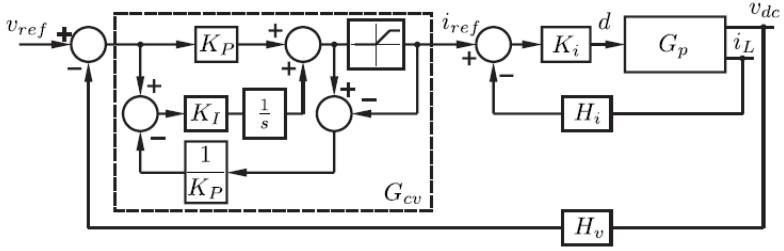
- The bending circuits are expected to cost approximately 55% of the overall budget.

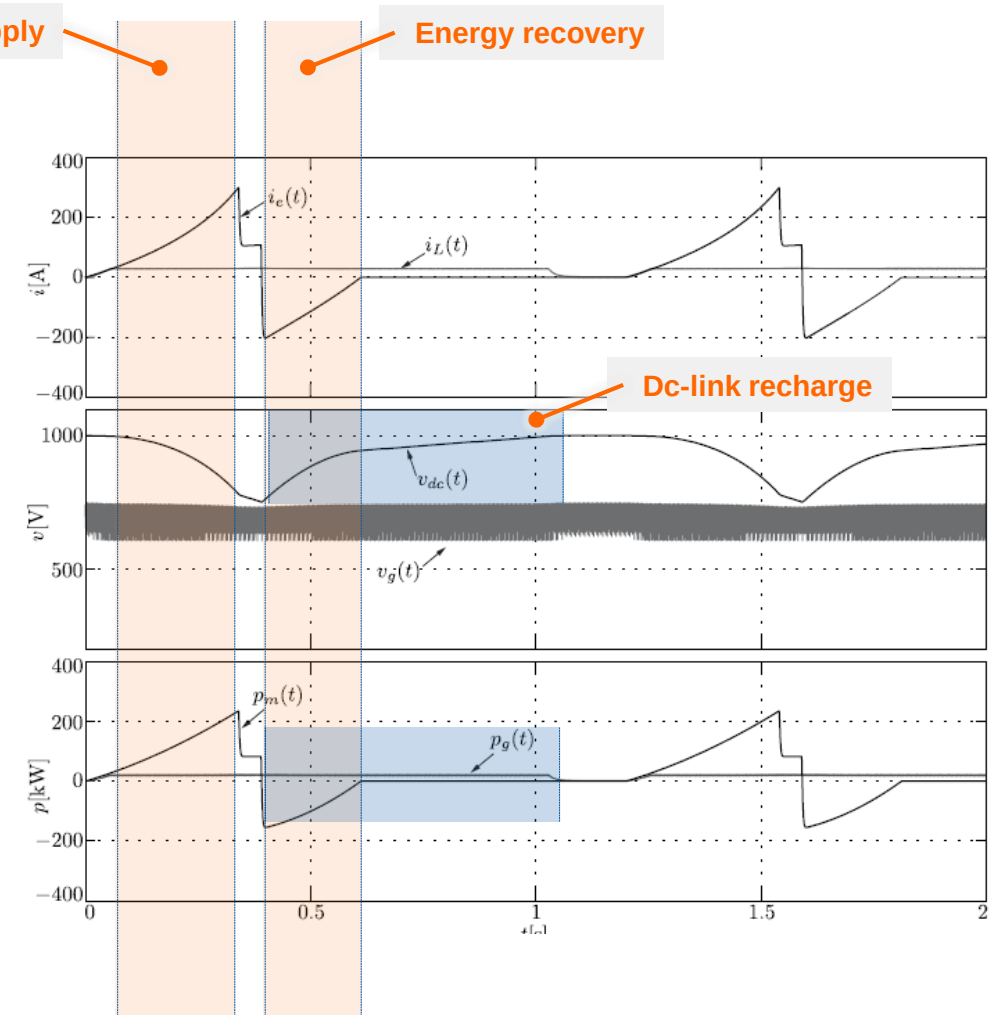


Annex

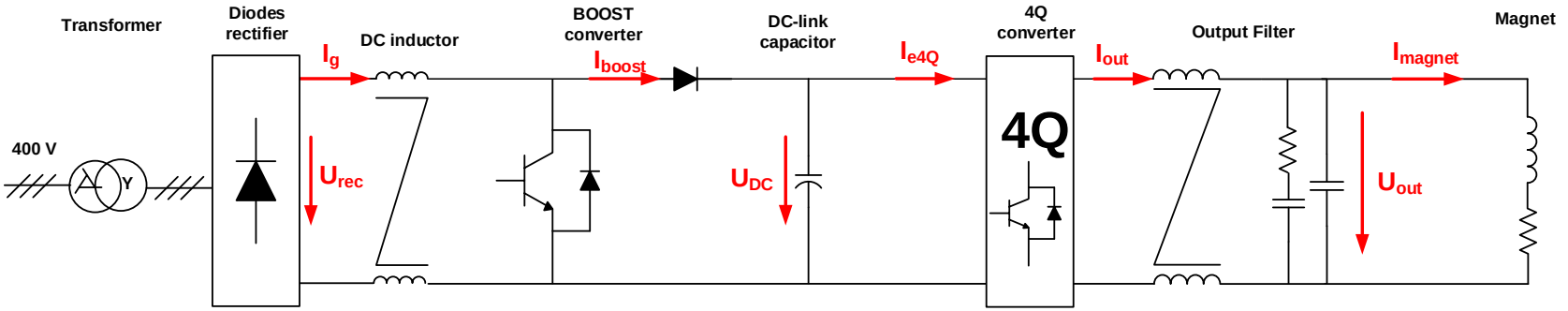
Limited grid power strategy

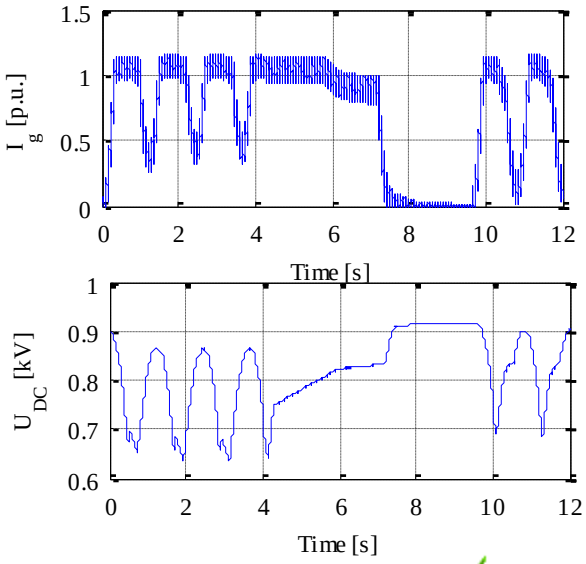
$$i_{Lmax} = \frac{I_{REF}^2 \, R_m}{V_g}$$



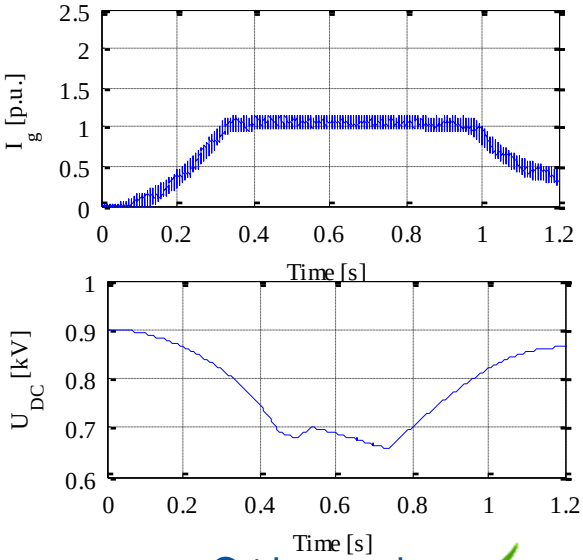


Grid disturbances

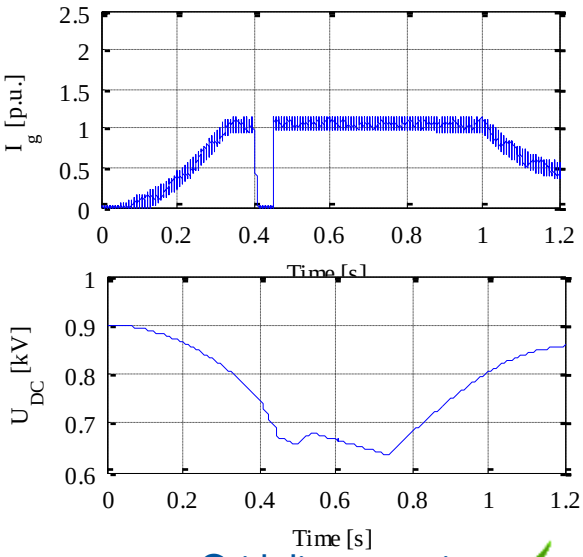




Nominal grid ✓



Grid overvoltage ✓
(0.4s – 0.5s)

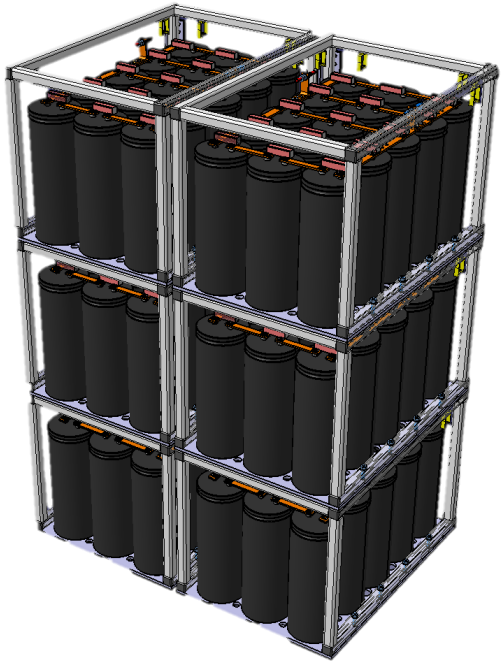


Grid disconnection ✓
(0.40s – 0.45s)

CERN

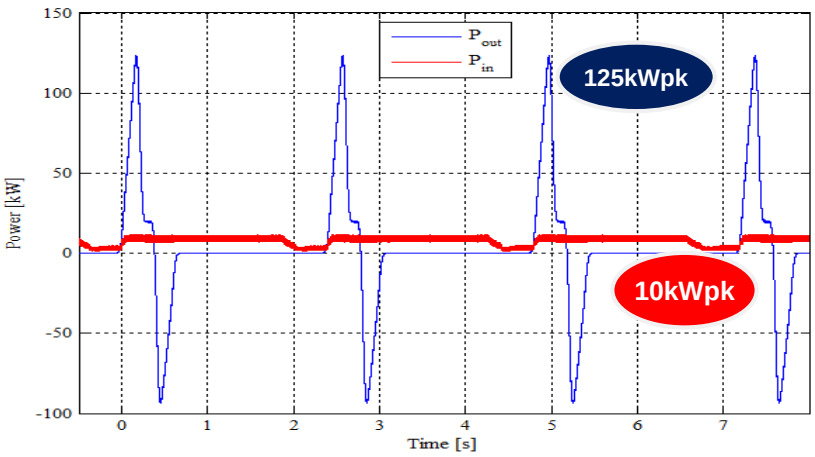
SIRIUS

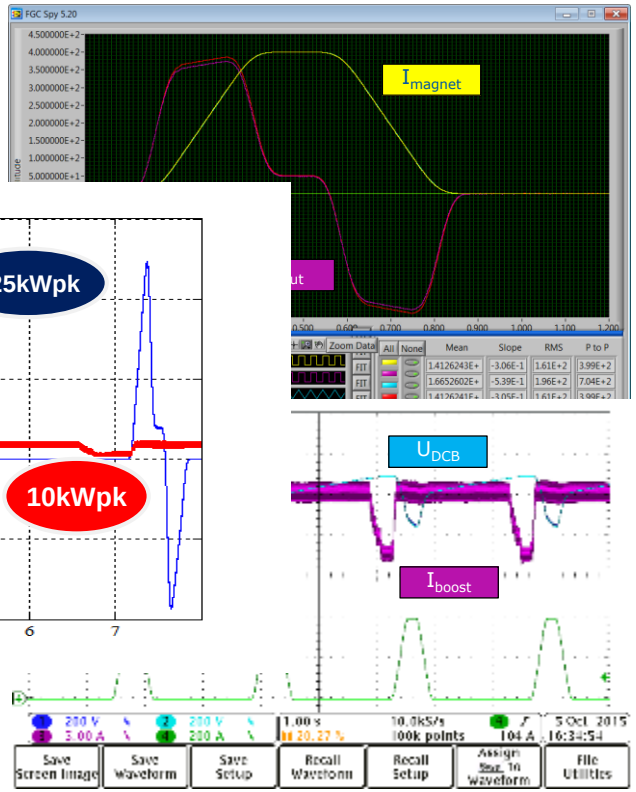
Energy storage module



- Energy/capacitor
  - Theoretical at 400V → 2320J
  - Actual (tol.-15%) →1972J
  - Operating at 300V → 1660J
  - Usable 300V to 200V→ 616J
- Energy/module (15 caps)
  - Theoretical → 34800J
  - Usable →9243J
- Maximum 3 modules per brick
- Customisation to increase total energy to 1MJ

SIRIUS proof-of-concept





https://edms.cern.ch/document/1506381/1

The SIRIUS converter