18 kA / ±10 V Power converter Project status

Serge PITTET, Jean-Paul Burnet

Technical Coordination Committee – CERN - 05/04/2018

Outline

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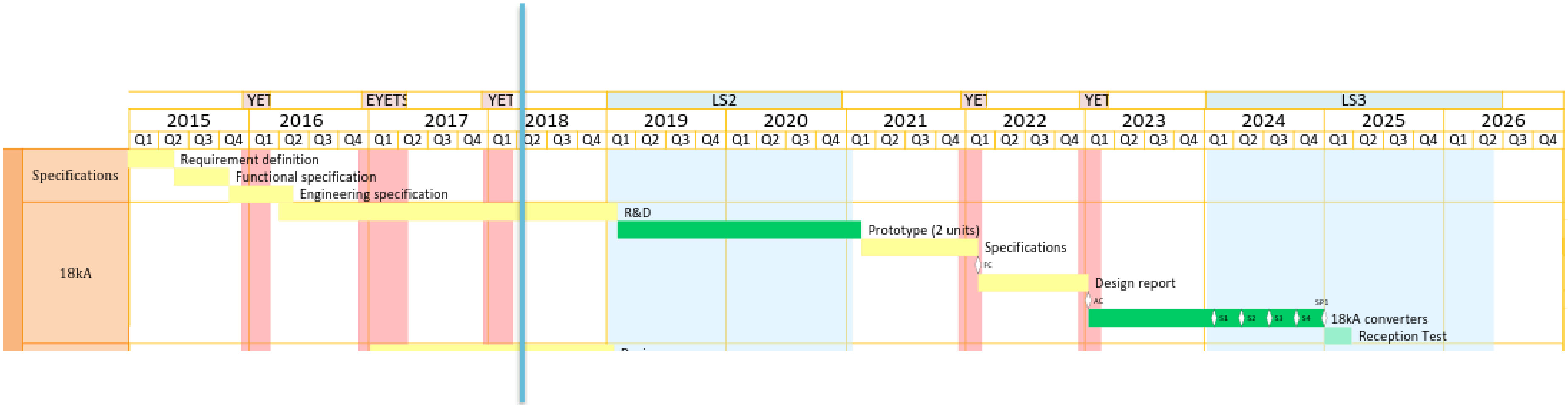
  - Schedule.
  - Ressources.
  - System Description.
- Converter overview
  - Typical waveform.
  - Project requirements.
  - Topology selection.
  - R&D situation.
- Technical highlights
  - Energy Storage System.
  - Crowbar.

Project background

- Purpose:
  - Provide a 18kA 2-quadrants power converter for the HL-LHC inner triplets, to ramp down in the shadow of the main LHC dipole magnets.
- Deliveries:
  - 2 prototypes (end 2020).
  - 4 +1 operational power converters (LS3).
- Budget:
  - 2 MCHF for 2.op prototype power converters.
  - 2 MCHF for 5 (4.op +1.sp) power converters.
  - 500 kCHF for 1.sp set of Power modules + DCCT + ctrl elec. units (Crate, FGC, RegFGC cards).

Master Schedule

- R&D phase ongoing.



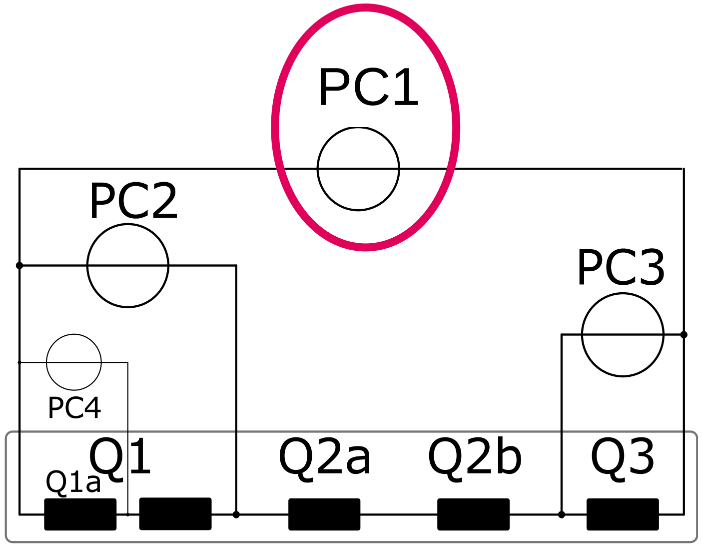
- In-line with EVM.

Manpower Resources (2018-03 estimate)

		Run 2		LS2		Run 3			LS3			
		2017	2018	2019	2020	2021	2022	2023	2024	2025	Total	
Required	Engineer_{staff}	0.1	0.2	0.6	0.6	0.9	0.7	0.6	0.5	0.5	4.6	22.5
	$\text{Technician}_{staff}$		0.3	0.8	0.8	0.5	0.5	0.5	0.8	0.8	3.2	
	Fellow		0.7	1.0	1.0	0.8					2.5	
	TTE		0.2	1.0	0.8						2.8	
	External	1.0	3.9	2.4							7.3	
Affected	S. Pittet	0.1	0.2	0.2	0.1	0.4	0.7	0.6	0.5	0.5	3.3	15.7
	L. de Mallac			0.4	0.5	0.5					1.4	
	M. Gros		0.5								0.5	
	M. Sardano		0.3	0.8	0.8	0.5	0.5	0.3			3.2	
	External	1.0	3.9	2.4							7.3	
Planed	$\text{Technician}_{staff}$							0.2	0.8	0.8	1.0	6.8
	Fellow		0.2	1.0	1.0	0.8					2.5	
	TTE		0.2	1.0	0.8						2.1	

System description

- Baseline scheme for the Inner-Triplet magnets powering.



Converter	PC1	PC2	PC3	PC4
Output current [A]	18000	±2000	±2000	±35
Output voltage [V]	±10	±10	±10	±10* *under discussions

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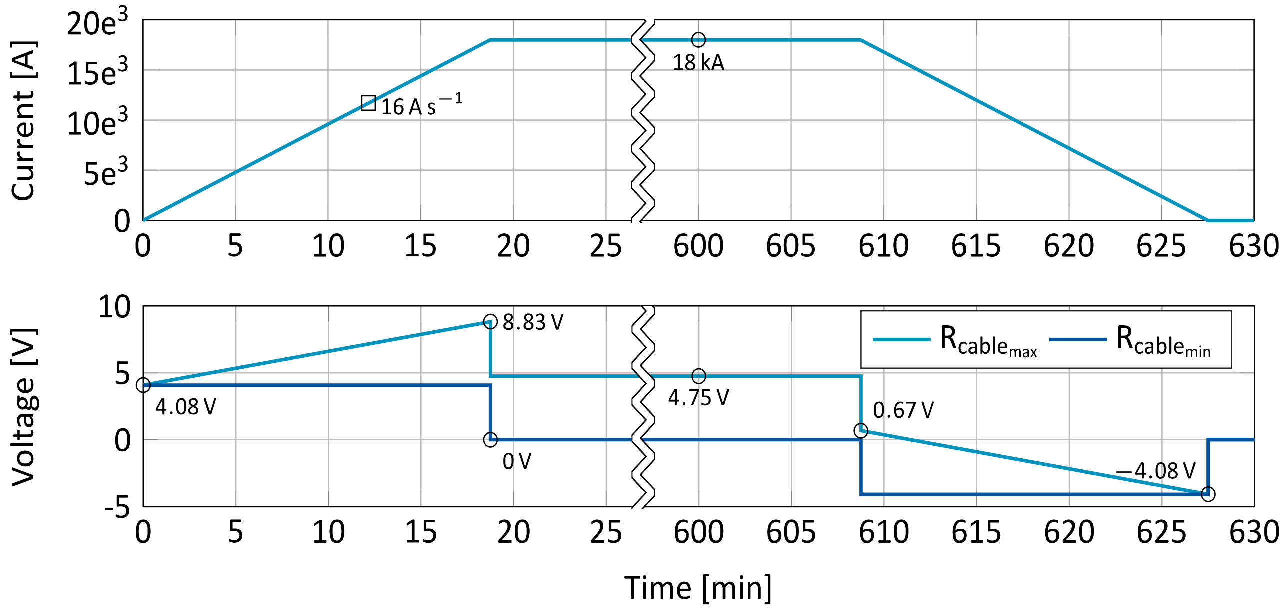
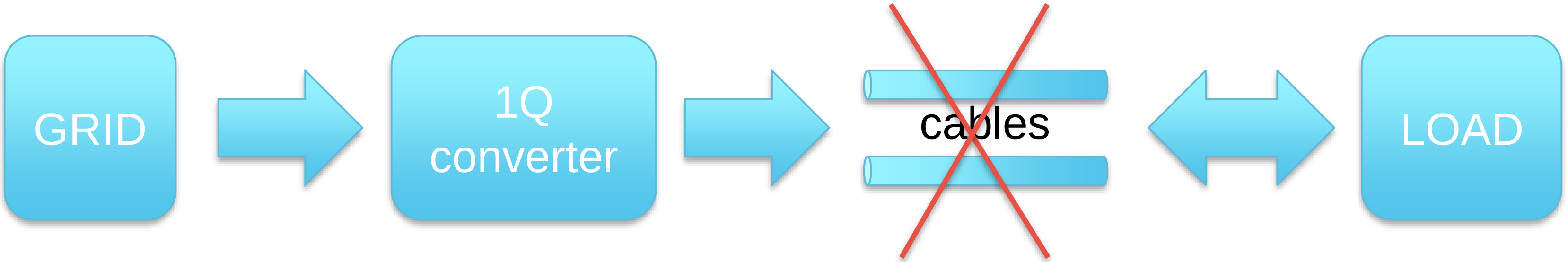
Typical waveform

- Ramp-up from 1 kA to 18 kA at 16 A/s (~18 min).
- Flat-top operation lasts for an average of 15 hours.
- Ramp down from 18 kA to 1 kA in the shadow of the main LHC dipole magnets (~20 min).



Project Requirements

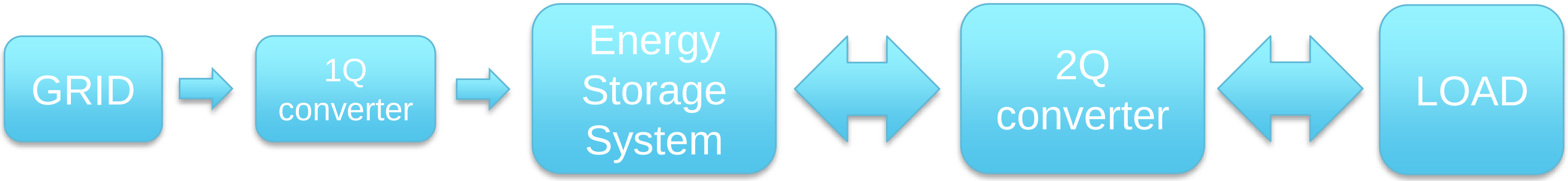
- Ramping down the current in the magnet is mainly done using the resistance of the cables - LHC case.



- With the new SClink, a 2-quadrant converter is required to recover the magnets energy (40 MJ).

Topology selection

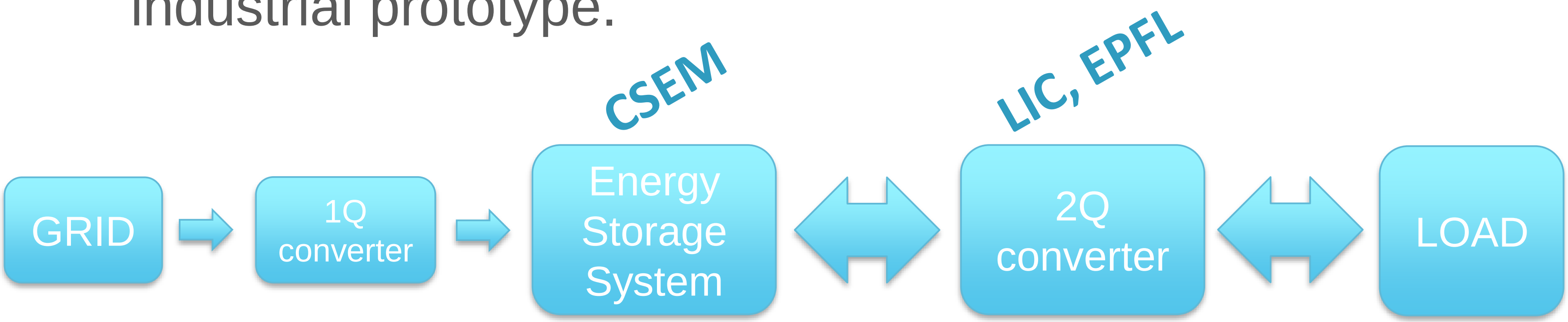
- A new 2-quadrant design of high current converter with integrated energy storage is proposed.



- It reduces the peak power drawn from the network from 200 kW down to around 40 kW, and minimizes the cost of electrical infrastructure.
- It increases the immunity to grid perturbations.
- It eases the control of the power flow.

R&D situation

- Overall structure and sub-components topologies have been defined.
- Three collaborations - EPFL, LIC, CSEM - agreements ongoing for the output stages.
- One collaboration under preparation for a full scale industrial prototype.



- CERN design for the global integration and specific items: DCCT rack, crowbar, separator, power racks, control.

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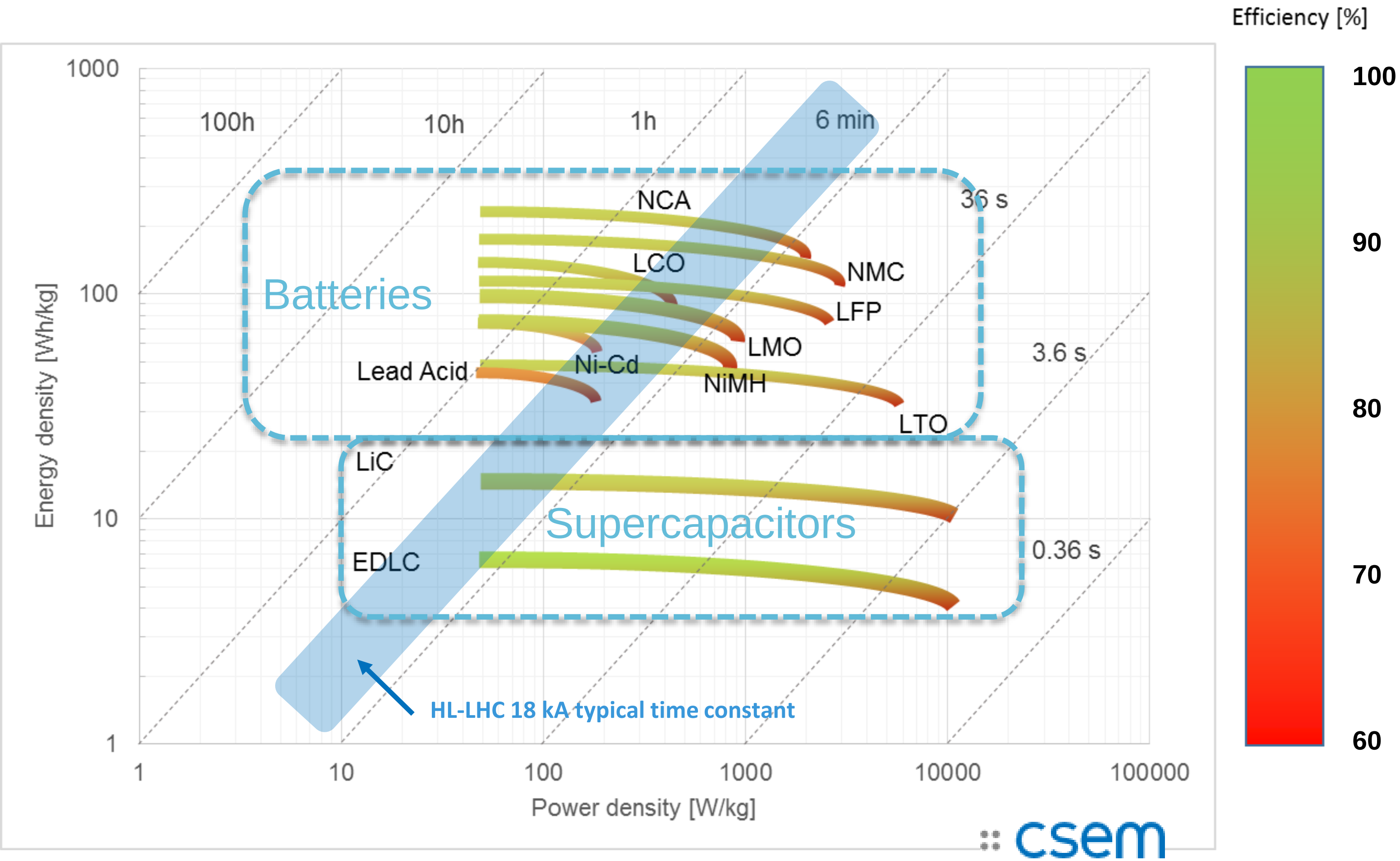
Energy Storage System
Efficiency Ragone plot (gravity densities)

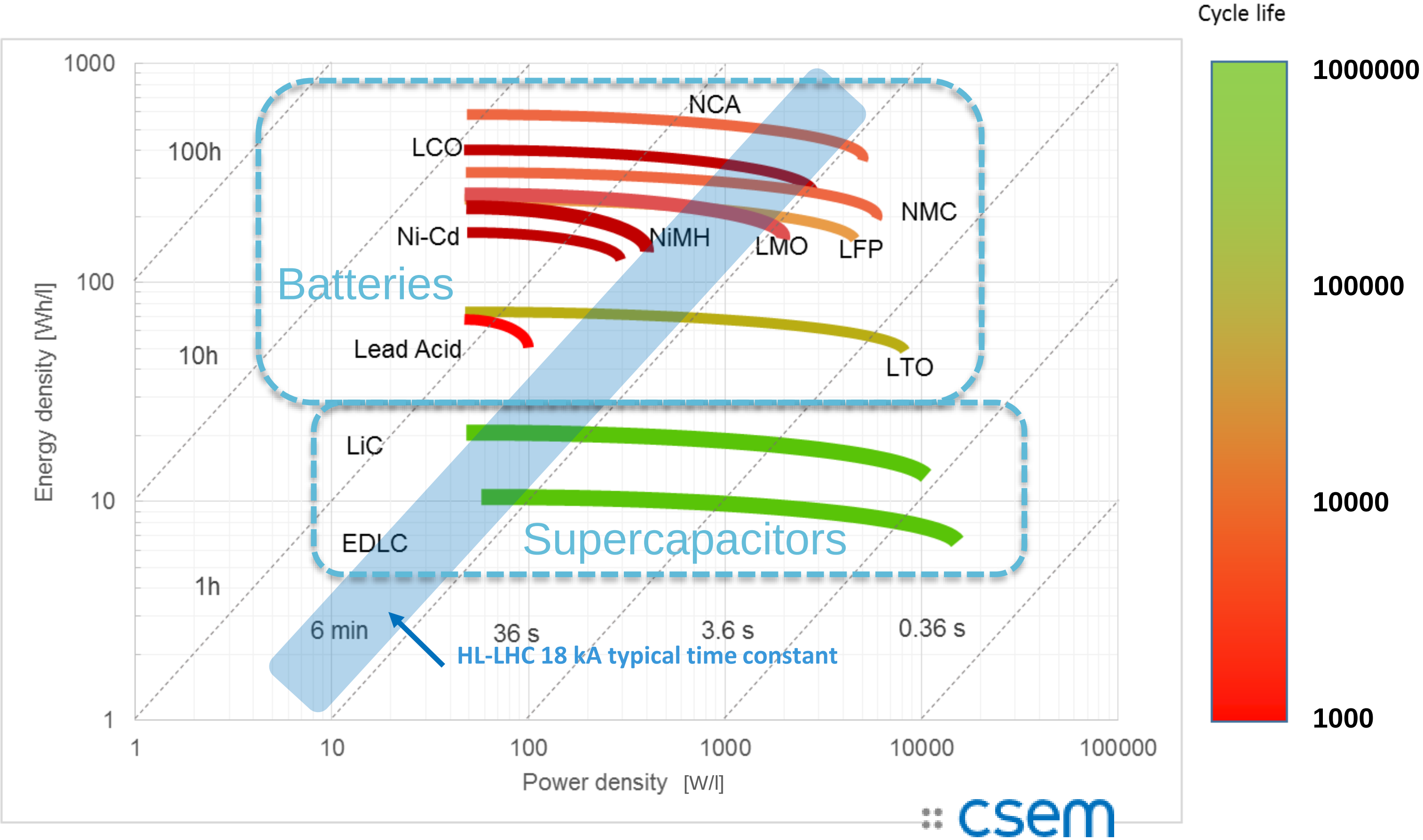
- Most of the technologies can provide a reasonable efficiency.



Energy Storage System
Cycle life Ragone plot (gravity densities)

- Only three candidates can provide the expected lifetime:

  Lithium titanium oxide batteries (LTO), Supercapacitors (LiC and EDLC).



Energy Storage System Candidates selection

	EDLC Supercapacitors	LiC Supercapacitors	LTO Batteries
Weight [kg]	2500	1390	900
Volume [l]	2550	1200	700
Number of racks	5	2-3	2
Total cell price [€]	250k	216k	40k + BMS
Cycle life	1M	>200k	>75k

- LTO is the most cost and size effective technology for this application.
- Multiple suppliers:

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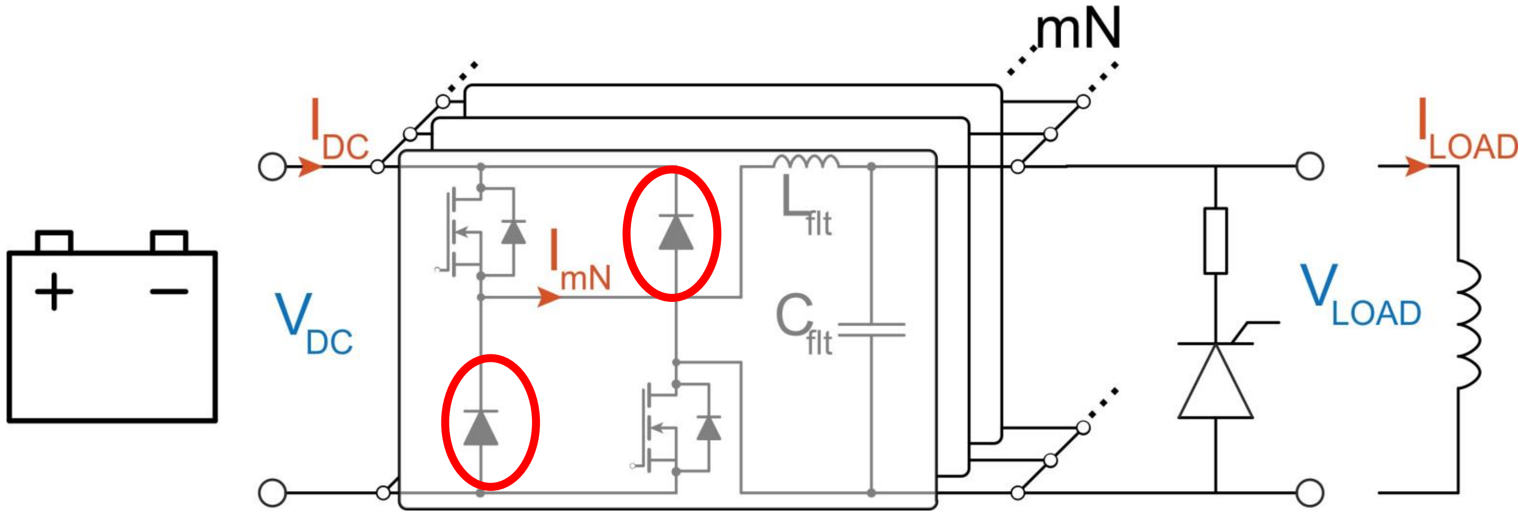
Crowbar Requirements

- In case of fault, the crowbar system shall be able to ramp down once the current. Even without electricity and cooling water, the blackout case.
- Pending request to increase the crowbar voltage from 10 V to 50 V is currently being analyzed, since impacting strongly converter design & performance (followed by the MCF).
- High precision is required at the output of the converter (accuracy class 0, Current ripple < 20 mA_{rms}).

Crowbar
Technical constraints

- The converter will be made of *N* sub-converters composed of *m* branches (*N* x *m* > 100).
- Because of the free-wheeling diodes, the load voltage $|V_{LOAD}|$ cannot exceed the DC-bus voltage V_{DC}.
- Normal operation requires a DC-bus voltage V_{LV} around 12V.
- Increasing the crowbar voltage would increase the output ripple, power losses, converter size and crowbar peak power.



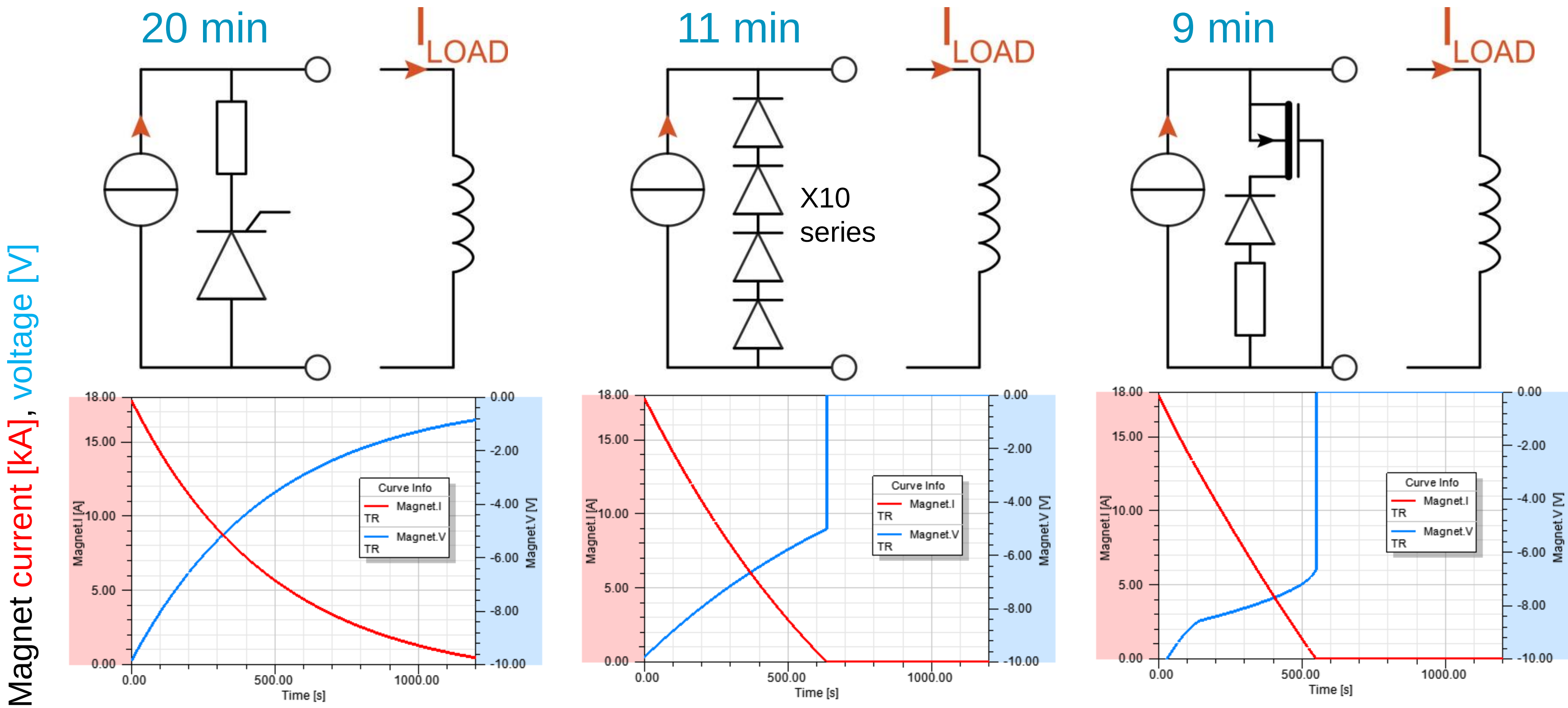
Crowbar Mitigation

- Alternative schemes could speed up the ramp down without increasing the peak output voltage.

Thyristor based
20 min

Diodes based
11 min

MOSFET based
9 min



Conclusion

- The overall structure and sub-components topologies have been defined.
- A battery technology has been identified.
- The conceptual study is ongoing. Design of the power converter to be started in 2019.
- The crowbar ratings are being reviewed by the MCF.

- Next steps:
  - Approval of the functional specification (end 2018).
  - Validate the demonstrators (end 2019).
  - Finalize converter integration (end 2019).

HiLumi HL-LHC PROJECT

Thank you for your attention

- Comparative Study of two-quadrant DC/DC stage in power supply for superconduction magnets (ICIT-IEEE 2018, edms 1918772).
- High-Current Low-Voltage Power Supplies for Superconducting Magnets (EE 2017, edms 1832844).
- HL-LHC 18 kA: ESS pre-study (CSEM, edms 1926350).