New generation of energy extraction systems for HL-LHC

Bozhidar Panev TE-MPE-EE

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OUTLINE

- Introduction
  - HL-LHC circuits that will need EE systems
- Details from the development phase and performance
  - Semiconductors based EE systems
  - Vacuum switches based EE systems
- Summary

General information

- HiLumi circuits per IP side that need EE systems

	Circuits for HiLumi	Magnet Type	I Ultimate (kA)	Number of circuits per IP side	Quench Heaters	EE
IT	Orbit correctors CP - vertical	MCBXFA	**1.73**	**1**	Baseline	Baseline
	Orbit correctors CP - horizontal	MCBXFA	**1.59**	**1**	Baseline	Baseline
	Superferric, order 2	MQSXF	**0.2**	**1**	no	Baseline
D2	Orbit correctors D2	MCBRD	**0.54**	**4**	no	Baseline

MCF table

- In total: 28 EE systems (7 per IP side)

- EE team strategy:
  - 2kA EE systems – for MCBXFA
  - 600A EE systems – for MQSXF and MCBRD

Switching technology selection criteria for HL-LHC

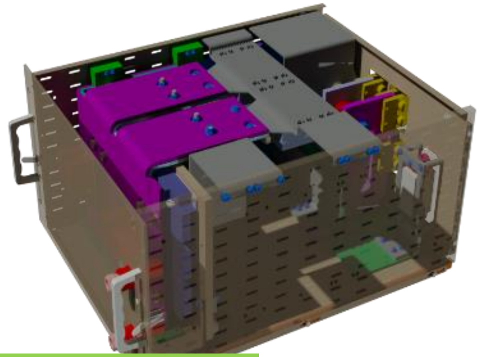
- Opening time: HL-LHC circuits require fast EE systems
  - LHC → (10-20)ms
  - HL-LHC corrector circuits → few milliseconds
- Maintenance free EE systems
  - Electromechanical circuit breakers currently in operation require a regular maintenance once per year
- Long service life → at least 20 years of operation
  - At least 10000 openings at nominal current guaranteed
- High reliability
- Design complexity
- Cost
- Development projects:
  - Semiconductor based EE systems
  - Vacuum switches based EE systems

EE systems based on semiconductors

2kA IGBT based EE systems (1)

- The IGBT (**I**ntegrated **G**ate **B**ipolar **T**ransistor) is used as a solid state switch
- Design and development started in 2017
  - Modular approach is applied in the design
  - Single module commutates bidirectionally 1kA
  - Two modules connected in parallel for 2kA operation

IGBT



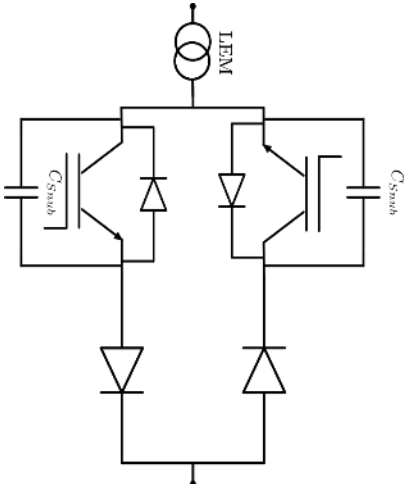
1kA module
housed in a 6U chassis

2 modules
In parallel

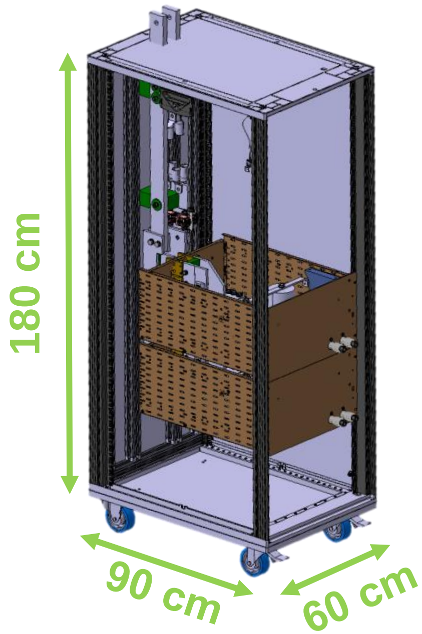
2kA IGBT based EE systems (2)

- Details from the design:
  - Dump resistor 300mΩ (2 x 600mΩ in parallel)
  - Bipolar operation of each 1kA module
  - ~2.5V voltage drop (still significant)
  - Redundancy achieved through 2kA triggerable fuse
    - 250us reaction
    - Low ohmic losses (200uOhms)

Dump resistors



1kA module configuration



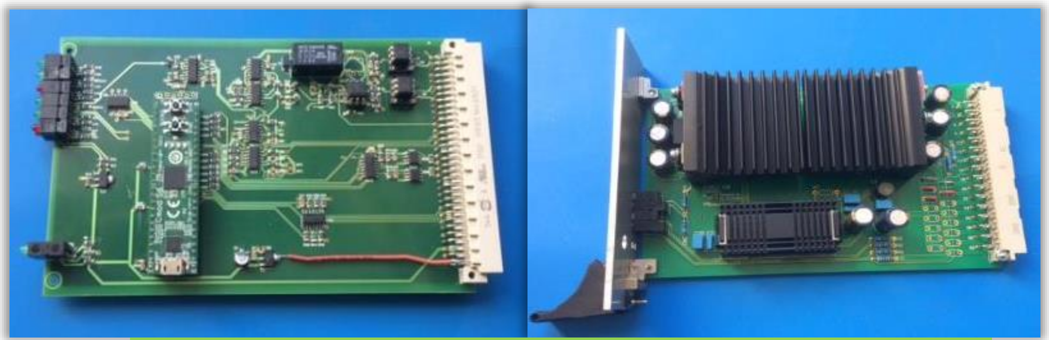
Back up protection with triggerable fuse

Control electronics IGBT based EE system

- Some details of the control electronics
  - sbRIO controller
  - Two FPA boards
  - Hardware interlock board
  - Power supply board

NI – sbRIO controller (single-board)
- 28 digital I/O
- 16 analogue inputs
- etc.

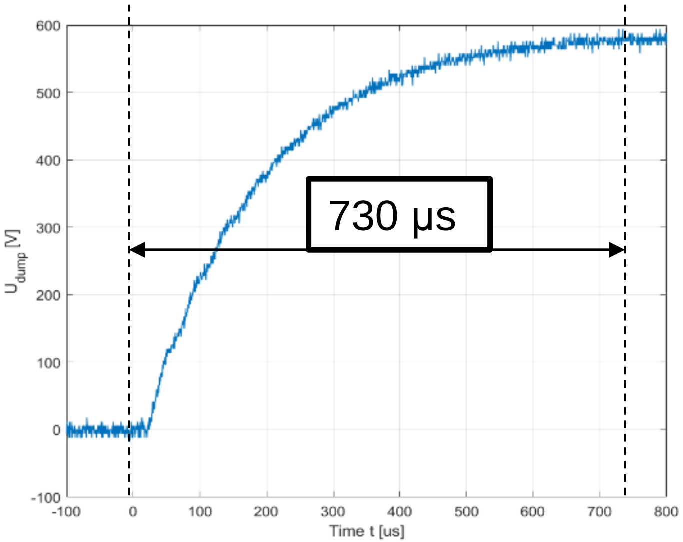
3U control chassis housed the electronic boards



FPA and PSU boards

2kA IGBT based EE systems for HL-LHC (3)

- **Semiconductor based (IGBT)** bipolar, compact and complete EE system to be used with the Hi-Lumi corrector magnets (MCBXFA & MCBXFB) at the vertical test bench in SM18
- Two systems (final version) fully tested were sent for installation in SM18
- Two more systems ordered in the industry – expected in Sep19



Performance at 2kA – U_DUMP

System under test in MPE lab.

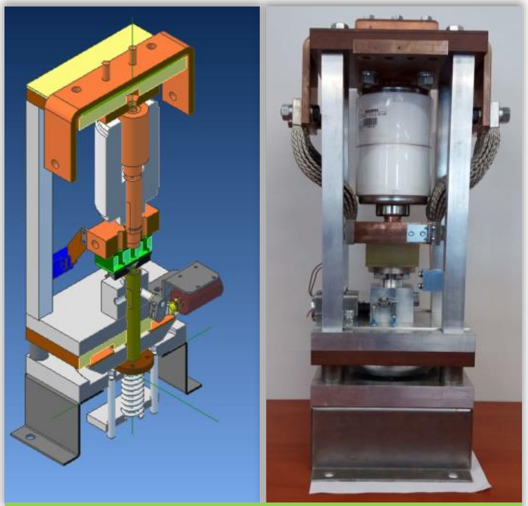
In SM18

EE systems with vacuum switches

EE system based on vacuum switches (1)

- Collaboration project between MPE-CERN and KAE-Lodz, Poland started in 2017
- Project included: Design and manufacturing of one EE system for 2kA and two EE systems for 600A
- In 2018: the prototypes were delivered and fully tested

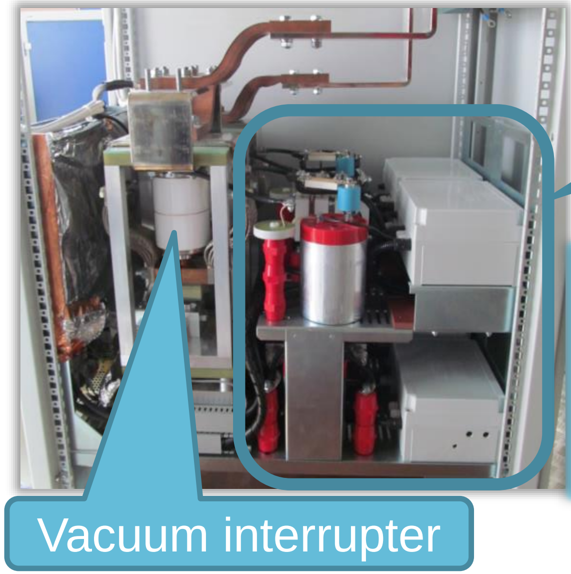
Two vacuum switches built in a sliding cassettes

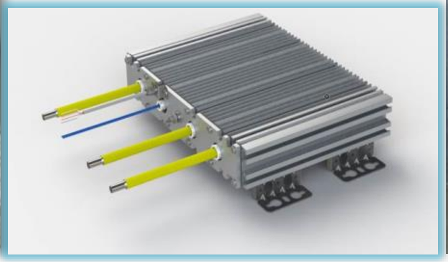


Vacuum interrupter

EE system based on vacuum switches (2)

- Two independently operating vacuum switches are connected in series and triggered simultaneously
- Integration of the EE systems is in the standard euro-rack (600x900x2000)





Dump Resistor

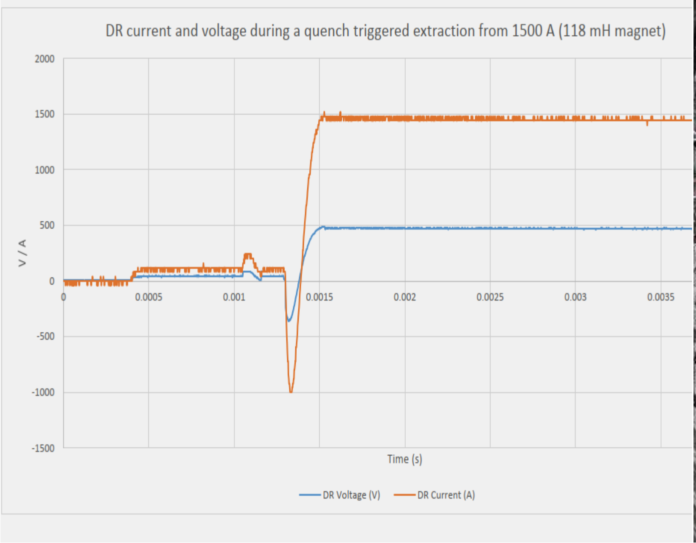
2kA EE system

2 system for 600A

Performance of vacuum switches based EE systems

- 2kA vacuum switches based EE system in real operation

EE operation during a training quench of MCBXFB at 1.5kA (15.03.2019) SM18
Circuit current transferred to resistor for ≈1.8ms



2kA system installed and commissioned in SM18 for protection of MCBXFB – 15.03.19

- Eight systems (pre-series order) delivered last month
  - 4 systems for 2kA
  - 4 systems for 600A
  - Acceptance tests currently ongoing

Pros and cons (IGBT vs Vacuum switches)

Parameters	IGBT	Vacuum switches
Lifetime	long service life (20 years)	long service life (20 years)
Maintenance	no	Twice for the whole lifetime
Water cooling	Yes (active water cooling) Water supply infrastructure is needed (20l/min per system)	No (natural convection)
Continuous power losses at 2kA	~ 5000W (2kA EE system)	~ 400W (2kA EE system)
Opening time	less than 1ms	less than 2ms
Redundancy	Yes (triggerable fuse)	Yes (all levels)
Zero-crossing	Nonlinear behavior	no issue
Control complexity	More complex electronics	
Cost	~ 20% more expensive	

Summary

- For tunnel installation in HL-LHC: Vacuum switches based EE systems
- For Superconducting test stations: IGBT based EE systems
- A “pilot” installation in LHC of 4 vacuum switches based EE systems for 600A is planned during LS2
- Apart from HL-LHC circuits, the vacuum switches based EE systems will replace in future the existing 600A corrector magnet EE facilities in LHC (EE systems strategy presented on TE-TM in April)

Thank You!

Additional slide (1)

- Principle of operation and performance at 2kA vacuum switches based EE system
  - The main current is transferred to the dump resistor in less than 2ms