Status of the new Energy Extraction Systems

Status Report

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OUTLINE

- Introduction
  - HL-LHC circuits that need EE systems
- Status of the EE system development
  - EE systems based on semiconductors
  - EE systems using vacuum switches
- Summary

General information

- HiLumi circuits per IP side that will 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

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

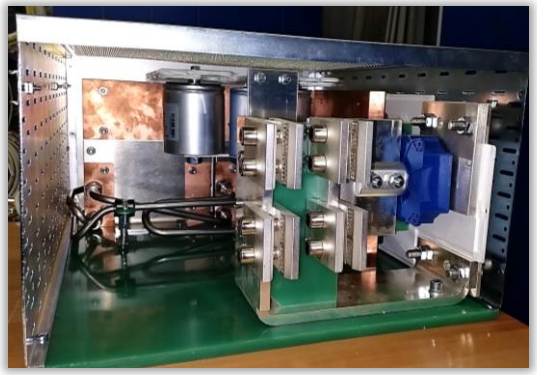
- EE team strategy:
  - 2kA EE systems – for MCBXFA
  - 600A or 1kA EE systems – for MQSXF and MCBRD

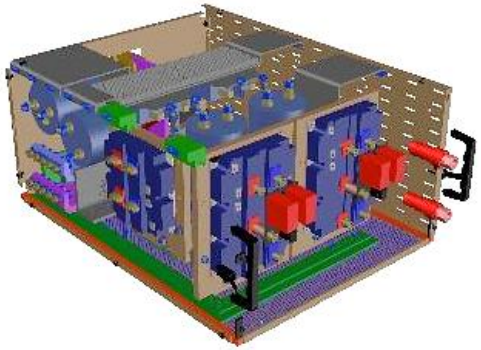
Status of the EE systems based on semiconductors

A few words about the semiconductor based EE systems

- The IGBT (**I**ntegrated **G**ate **B**ipolar **T**ransistor) is used as a solid state switch
- Modular approach is applied in the design
  - Single module commutates 1kA
  - Each module is housed in 6U chassis
  - One direction of the current only

IGBT





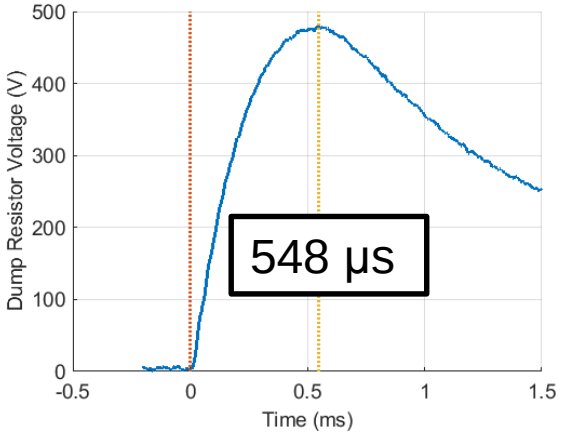
1kA module in 6U chassis

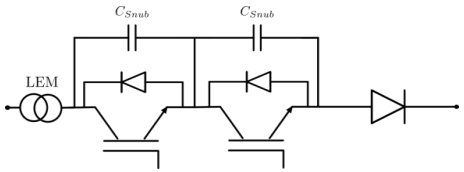
Courtesy Gert-Jan Coelingh, Vasilios Karaventzas

Status of semiconductor based EE systems

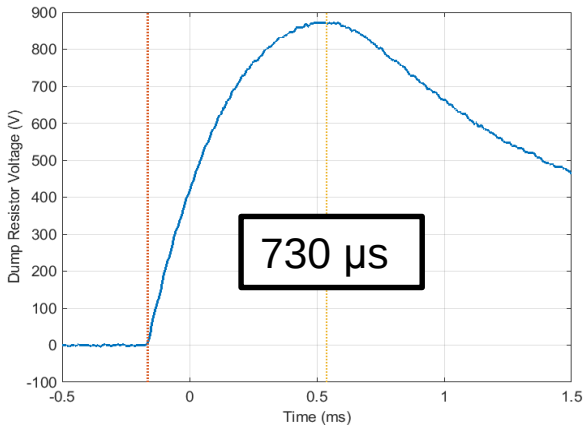
- In 2018, two prototype switch modules for 1kA were manufactured and tested on a warm magnet

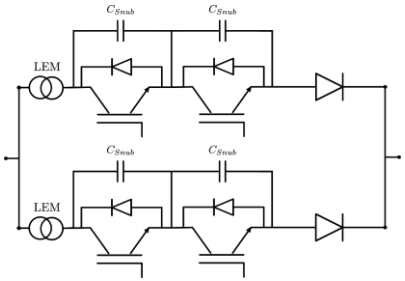
Performance at 1kA by single module – U_DUMP

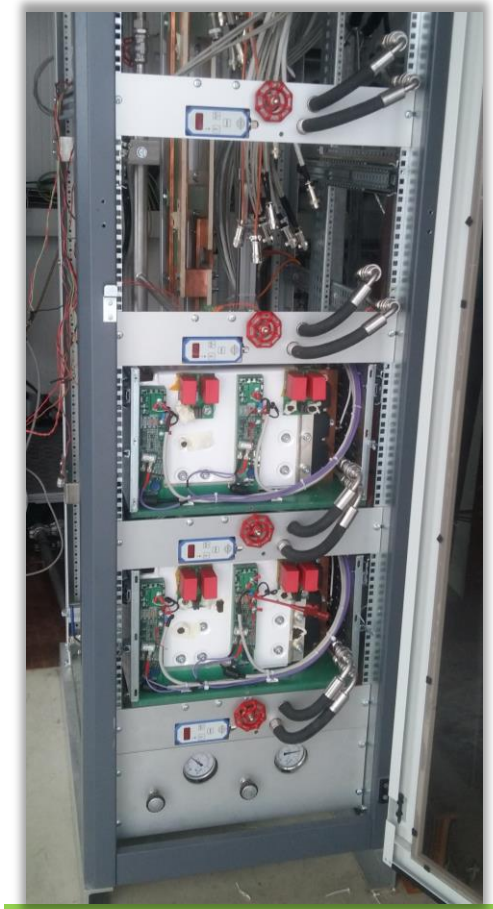




Performance at 2kA by two paralleled module – U_DUMP





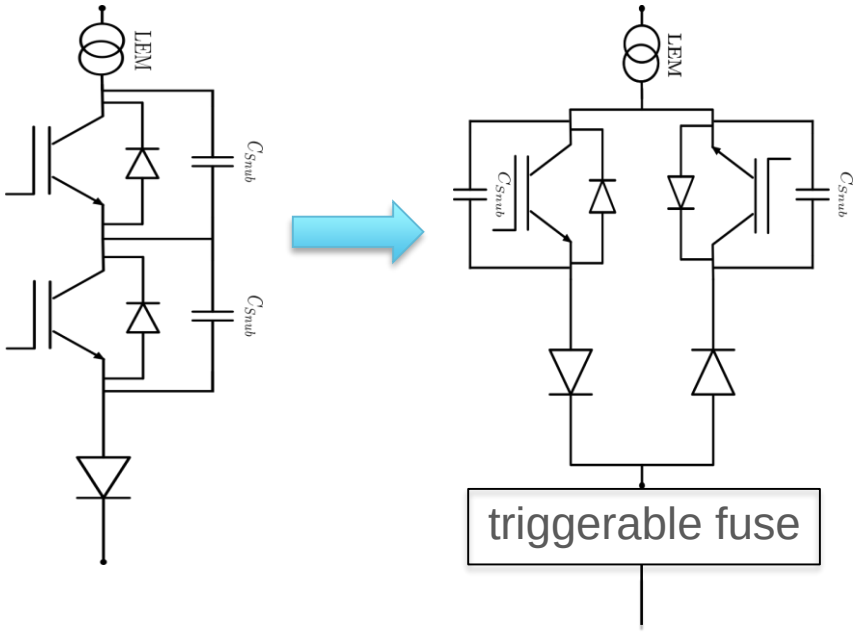


Two 1kA modules under test

Courtesy Gert-Jan Coelingh, Vasilios Karaventzas

Upgrade of 1kA IGBT switch design

- In order to reduce the on-state losses and ensure bi-directional operation, the 1kA module was updated
- In the previous version:
  - 2 IGBTs and a single diode in series
  - mono-directional operation
  - ~4V forward voltage drop
- The upgraded design:
  - 1kA bi-directional operation
  - ~2.5V voltage drop (factor 10 to classical EMCB)
  - No redundant IGBT
  - Redundancy achieved through 2kA triggerable fuse
    - 250us reaction
    - Very low ohmic losses

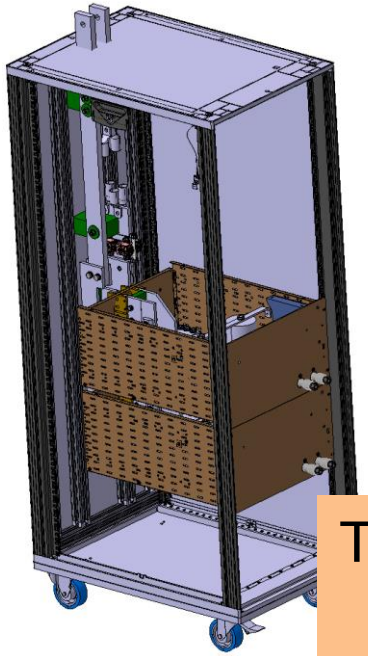


mono-directional bi-directional

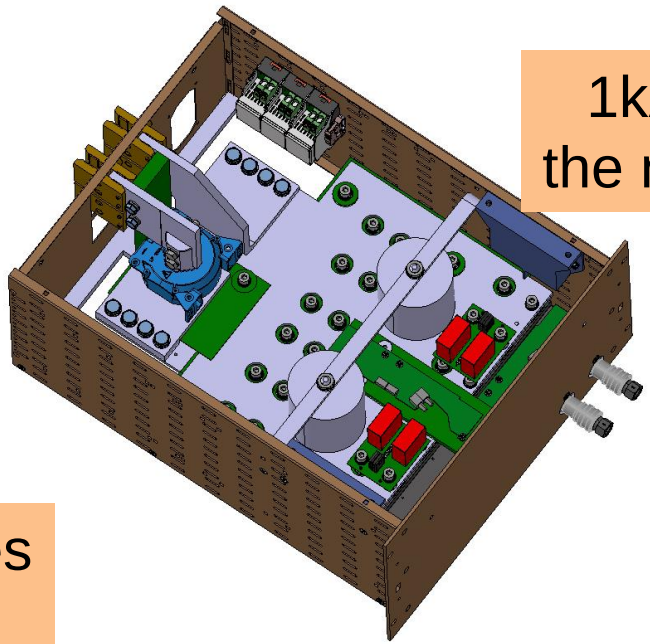
Courtesy Gert-Jan Coelingh, Vasilios Karaventzas

IGBT EE system – short summary

- The new (upgraded) design was finalized
- Two 1kA modules will be produced by the end of 2018
- Type tests start – Jan 2019
- Possibility of 2 circuits in one euro-rack → 50% less volume than before



Two 1kA modules in 19 inch rack



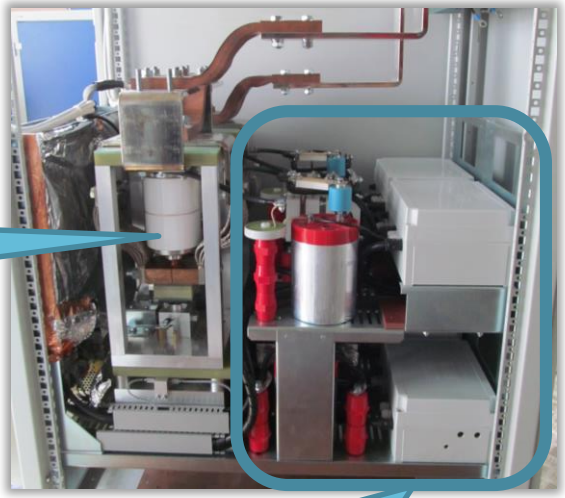
1kA module the new design

Courtesy Gert-Jan Coelingh, Vasilios Karaventzas

Status of the EE systems with vacuum switches

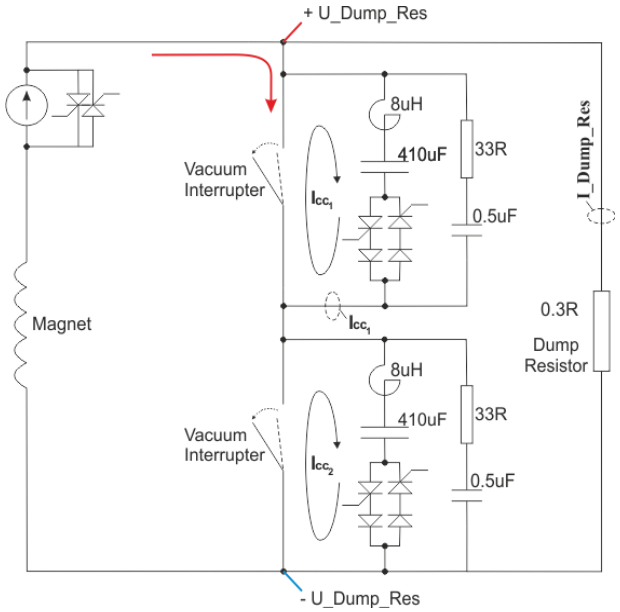
EE system based on vacuum switches

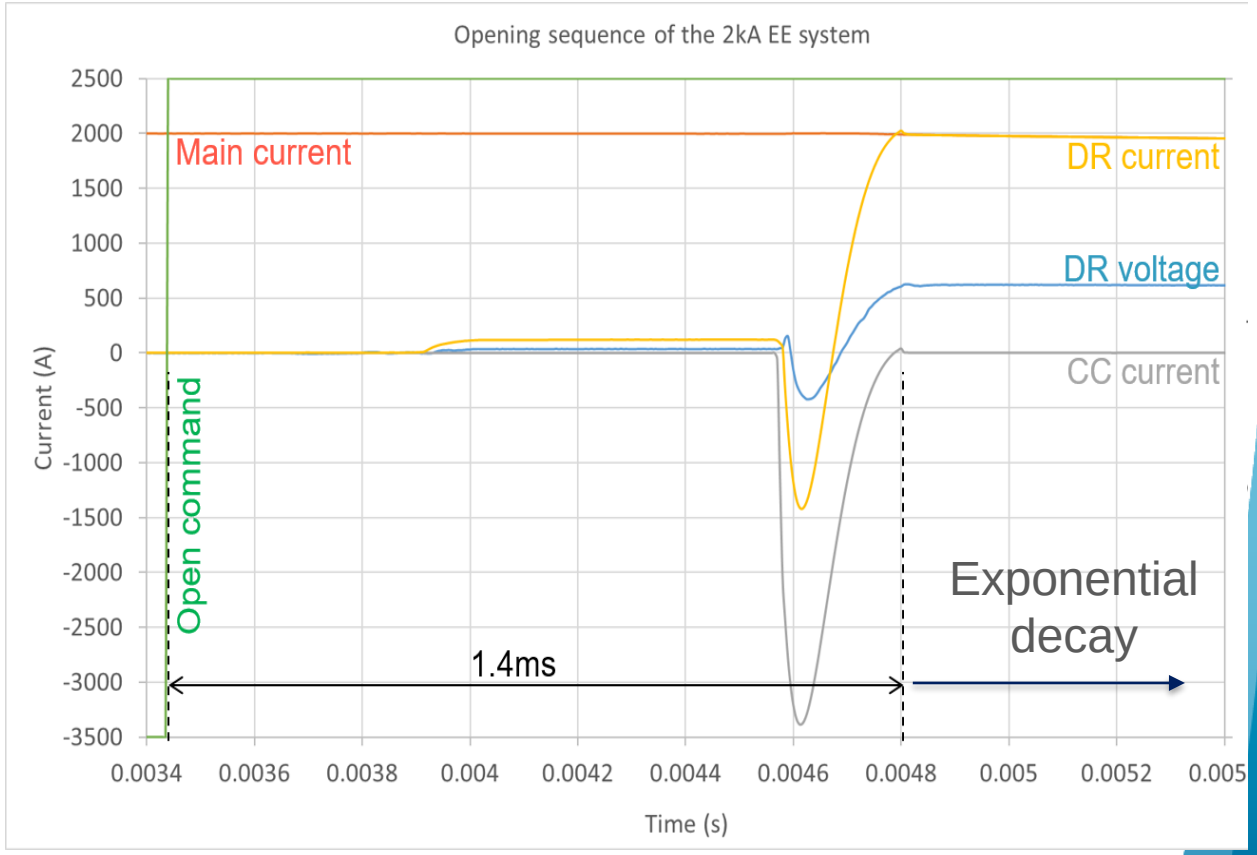
- Collaboration project between MPE-CERN and KAE-Lodz, Poland started in 2017
- Project includes: Design and manufacturing of one EE system for 2kA and two EE systems for 600A
- In 2018: the 2kA prototype was delivered and commissioned using 1mH, 1mΩ warm inductive load



Performance - 2kA EE system with vacuum switches

- Principle of operation and performance at 2kA
  - The main current is transferred to the dump resistor in less than 1.5ms





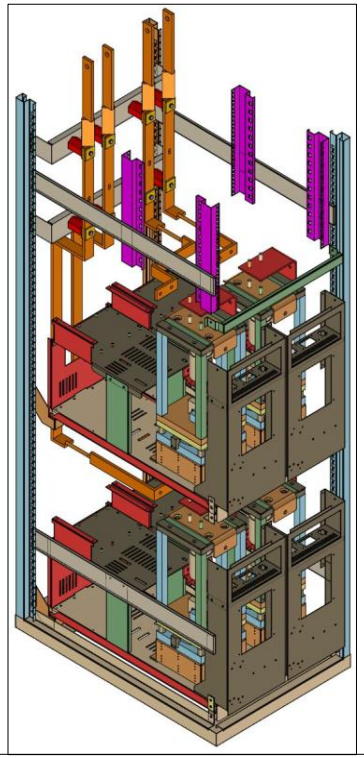
Validation tests - 2kA EE system with vacuum switches

- All performed tests passed successfully
- Around 1500 openings at different currents
- The EE system showed **fully repetitive and stable performance**
- The EE system satisfies the requirements for HL-LHC

Test	Results
HV test	Pole to pole: 1kV, 560MΩ; Pole to ground: 5kV, 2.5GΩ
Functional test - control chassis	Passed
Functional test - switches	Passed
EMC test (±4kV at 100kHz)	Passed
Internal resistance measurement	R ≈ 120μΩ
Total voltage drop at 2kA	In the range → ≈0.240V
Heat run test (2kA flowing for 10h)	Busbars max temp 70°C, electronics 35°C, ambient 25°C
External and internal interlocks	Tested successfully
Dump resistor energy deposition	Tested
Opening with current	More than 1500 cycles at different values of the current and different inductive load

Status of 600A EE systems based on vacuum switches

- Manufacturing and first tests - completed
- Expected delivery at CERN: end of October 2018
- Two systems in 1 EURO rack (600x900x2000)



Rack housing the 600A EE systems

Summary

- IGBT EE system
  - The tests with new (upgraded) 1kA module will start in beginning of 2019
  - The complete system will be ready for installation in Q2-2019
- EE system with vacuum switches
  - 2kA prototype was tested – showed very good performance
  - 600A prototype – delivery is expected end of Oct 2018
    - the type tests will be completed at the end of 2018
  - A pre-series of six systems (2 for 2kA and 4 for 600A) soon will be ordered to the industry
    - A price enquiry process - completed
    - Manufacturer - selected
    - Still some legal issues to be resolved

Decision

- Vacuum switches or IGBTs in HL-LHC EE systems?
  - Significant power losses of IGBTs even with the last upgrade (~4.5kW @ 2kA)
  - Vacuum switches system – only 480W losses at 2kA
  - IGBTs need water cooling system
  - Vacuum switches systems – natural convection

Decision:

For HL-LHC tunnel installation: Vacuum switches based EE systems

For superconducting test stations: IGBT based EE systems

Thank You!