Introduction to Magnet Powering and Protection

R. Denz, AT-MEL-PM

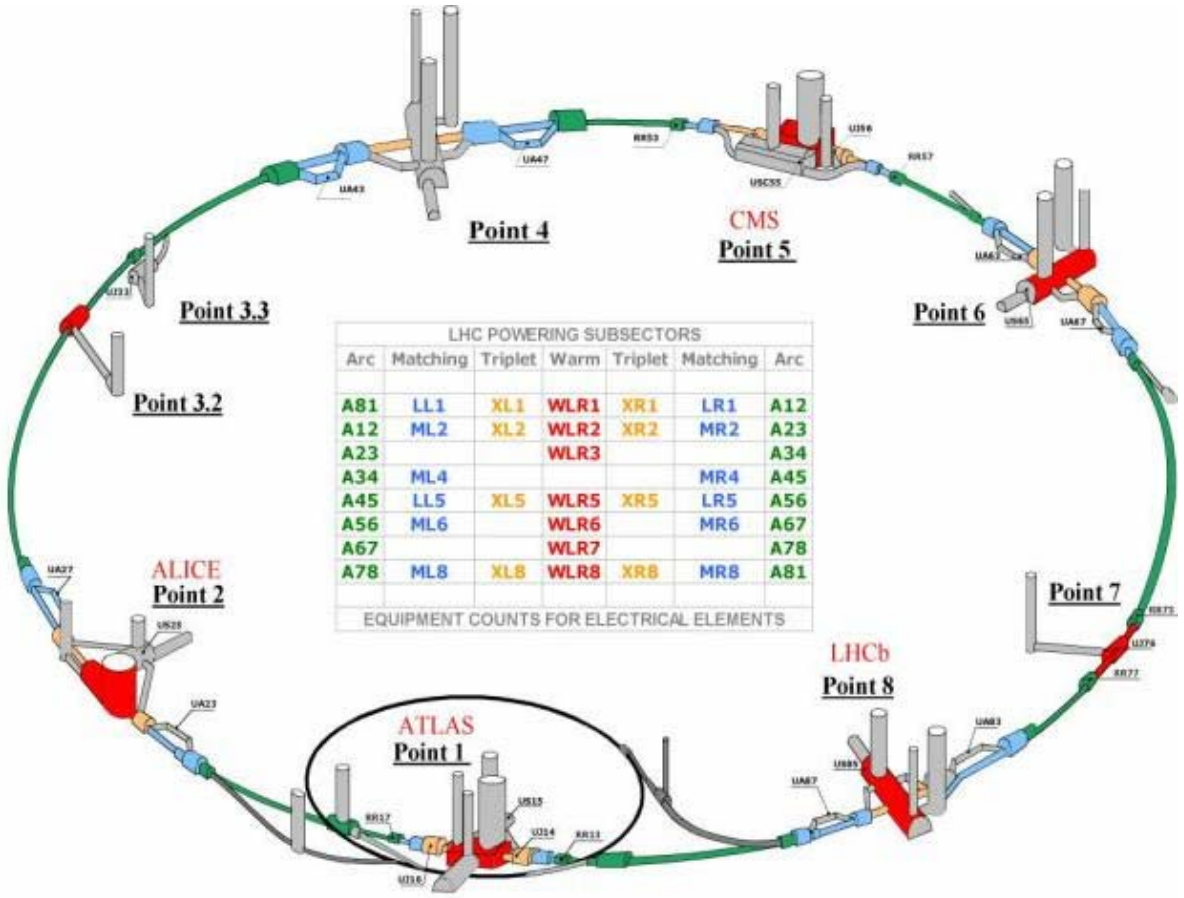
Outline

- Powering schemes for LHC superconducting elements
- LHC quench protection and energy extraction systems
- Interface to the Machine Interlock System
- Strategies for hardware commissioning

Further reading …

- Workshop on LHC Powering, CERN, 27-29 November 2000
- Review of LHC Power Converters, CERN, 6 June 2001
- Review of the LHC Quench Protection System, CERN, 5-7 December 2001
- LHC Machine EMC Workshop, CERN, 25 November 2004
- LHC Design Report, Vol. 1
- Machine Protection Review, CERN, 11-13 April 2005
  - Failures in Magnet and Powering Systems – R. Schmidt
  - Magnet Powering System and Beam Dump Requests – M. Zerlauth

Powering subsectors



LHC POWERING SUBSECTORS

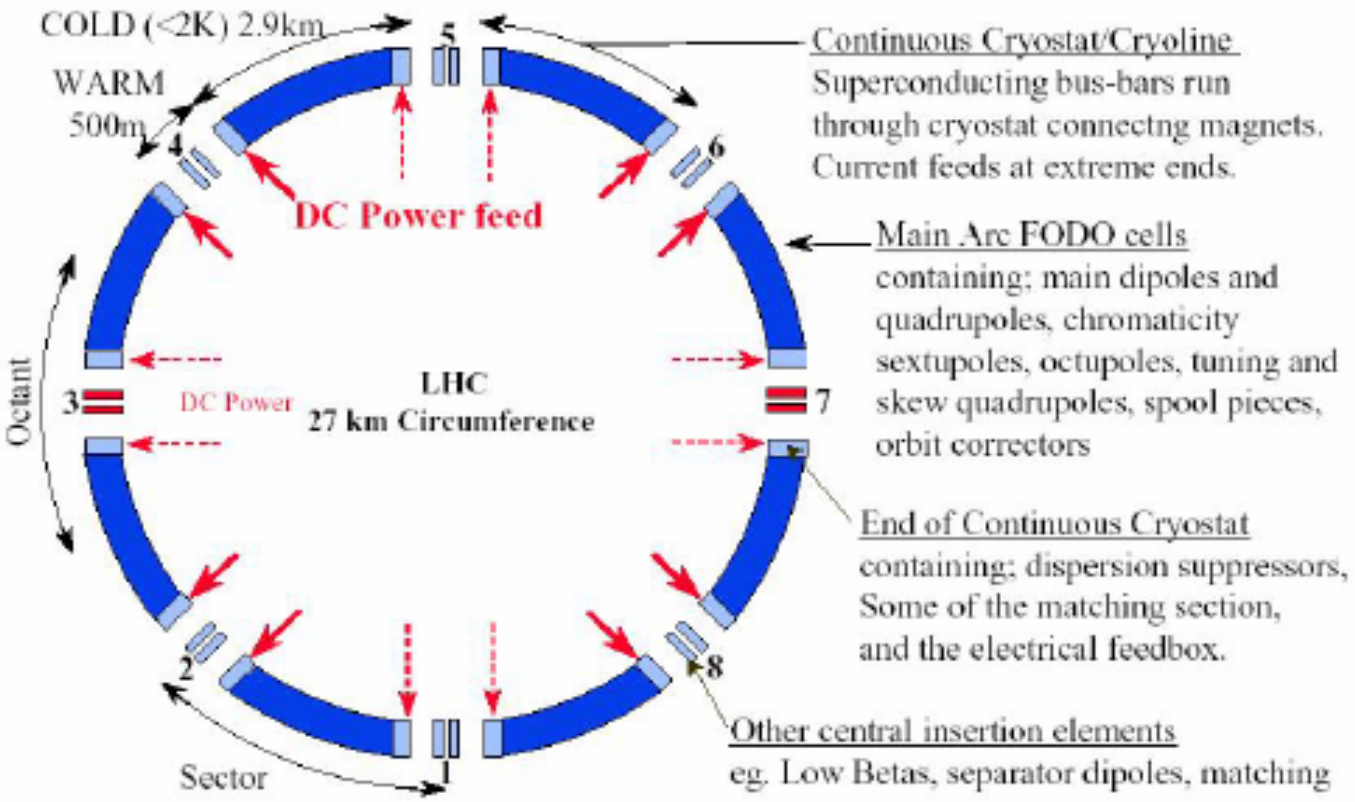
Arc	Matching	Triplet	Warm	Triplet	Matching	Arc
A81	LL1	XL1	WLR1	XR1	LR1	A12
A12	ML2	XL2	WLR2	XR2	MR2	A23
A23			WLR3			A34
A34	ML4				MR4	A45
A45	LL5	XL5	WLR5	XR5	LR5	A56
A56	ML6		WLR6		MR6	A67
A67			WLR7			A78
A78	ML8	XL8	WLR8	XR8	MR8	A81

EQUIPMENT COUNTS FOR ELECTRICAL ELEMENTS

Electrical Circuits Version : 1.4

- 28 powering subsectors
  - 8 arc powering subsectors, 8 inner triplets, 12 matching sections, 7 warm sections

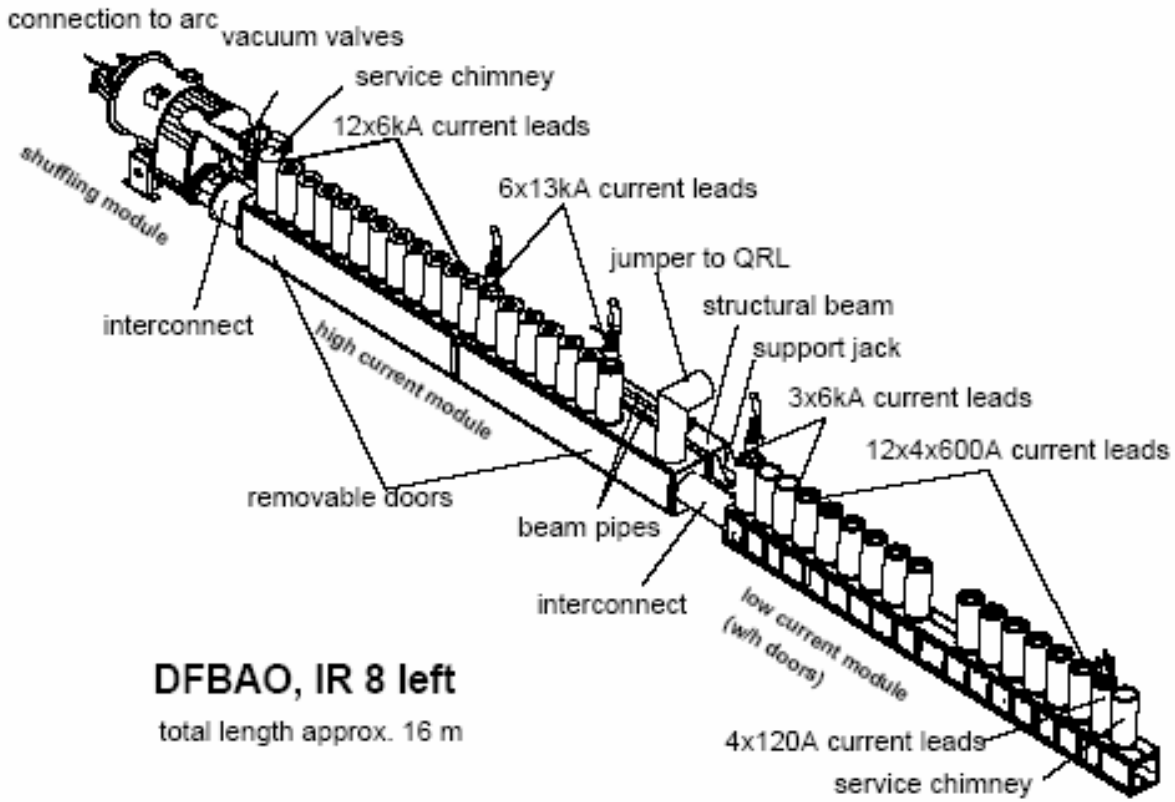
Powering of the arc cryostats



LHC Design Report, v 1, p. 252

➔ Main circuits RB, RQF and RQD powered from the even points

Electrical distribution feedboxes

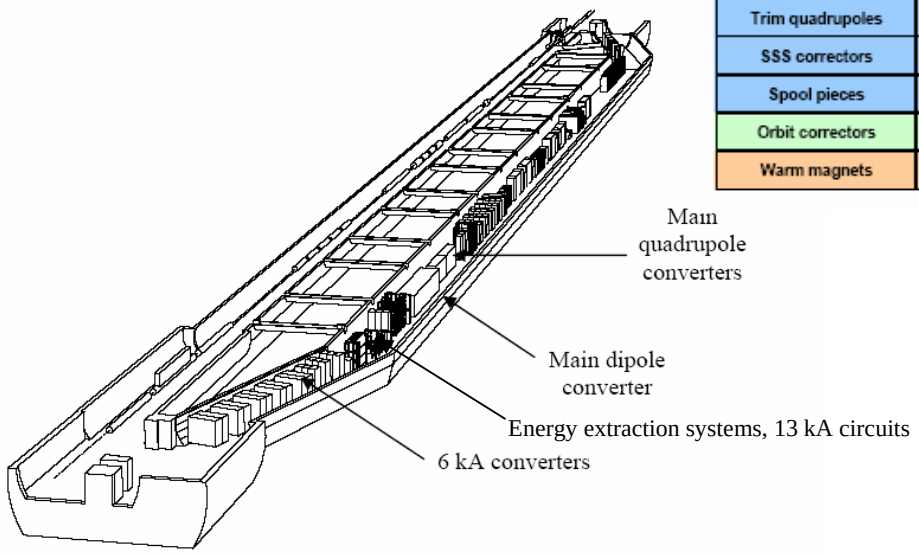


LHC Design Report, v 1, p. 260

➔ 16 DFBA, 23 DFBM, 5 DFBL and 8 DFBX

Powering areas and power converters

Circuit Type	Nominal Current (A)	Current Polarity	One Year Accuracy (ppm of Inominal)	One day Reproducibility (ppm of Inominal)	1/2 hour Stability (ppm of Inominal)	Resolution (ppm of Inominal)
Main Bends, Main Quads	13000	Unipolar	± 50 ± 20 with calibration	± 5	± 3	1
Inner triplet	8000/ 6000	Unipolar	± 100 (± 20 with calibration)	± 20	± 10	15
Dispersion suppressor	5000/ 6000	Unipolar	± 70	± 10	± 5	15
Insertion quadrupoles	4000/ 5000/ 6000	Unipolar	± 70	± 10	± 5	15
Separators (D1,D2,D3,D4)	5000/ 7000	Unipolar	± 70	± 10	± 5	15
Trim quadrupoles	600	Bipolar	± 200	± 50	± 10	30
SSS correctors	600	Bipolar	± 200	± 50	± 10	30
Spool pieces	600	Bipolar	± 200	± 50	± 10	30
Orbit correctors	120/60	Bipolar	± 1000	± 100	± 50	30
Warm magnets	650/1000	Unipolar	± 200	± 50	± 10	15



LHC Design Report, v 1, p. 275 & p 278

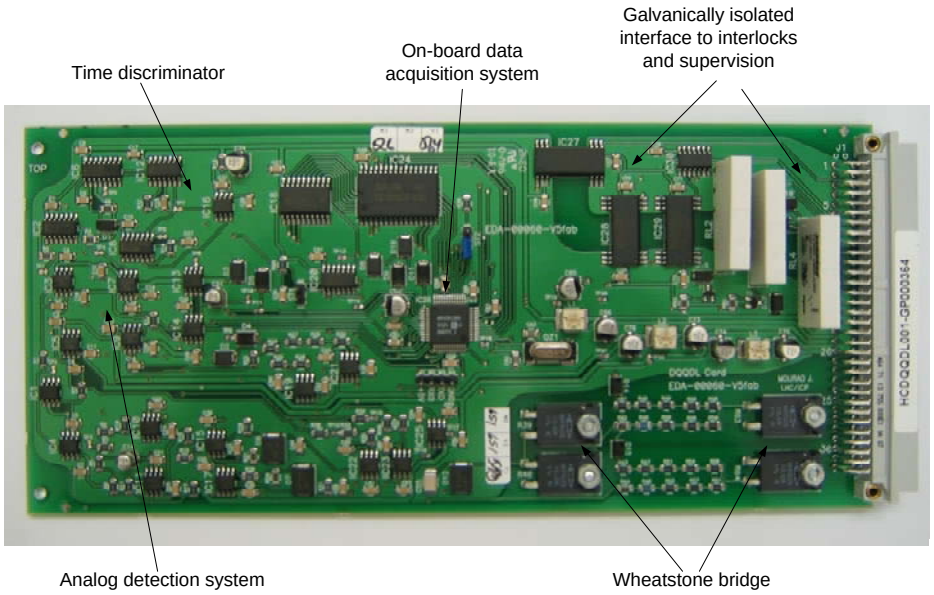
- Main power converters located in the former LEP RF galleries in the even points
- 1720 power converters in total, 22 different types

Protection of LHC superconducting elements

- Dedicated protection systems for all circuits with $I_{NOM} \geq 600$ A
  - Main dipoles and quads
    - Analog quench detectors + quench heater power supplies
  - Main busbars
    - Digital quench detector with distributed voltage pick-ups
  - HTS current leads
    - Individual protection by digital protection system
  - Insertion region magnets and busbars
    - Global protection of magnet and busbar by digital quench detector plus quench heater power supplies
  - Correctors and busbars
    - Global protection of magnet and busbar by digital quench detector
- Protection of 60 A and 120 A circuits by corresponding power converter

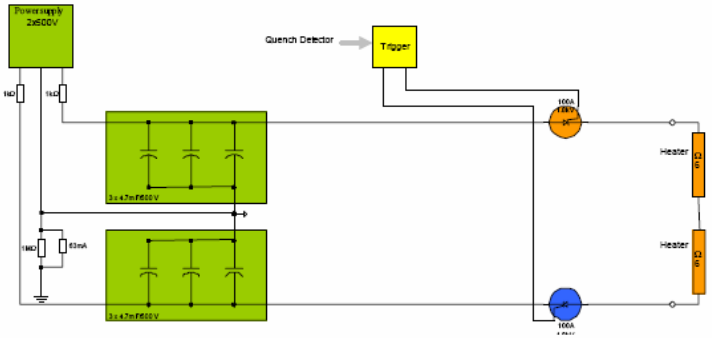
Protection of LHC main magnets: local quench detector

- Analog bridge detector based on state of the art instrumentation amplifiers
- (2 out of 2) || (2 out of 2) hardwired multi-channel evaluation scheme
- Radiation tolerant
- Adjustment free – fixed threshold detector
- Digitally isolated interface – detector circuit on magnet potential
- On-board data acquisition system
- Cost efficient (2500 circuit boards in LHC)

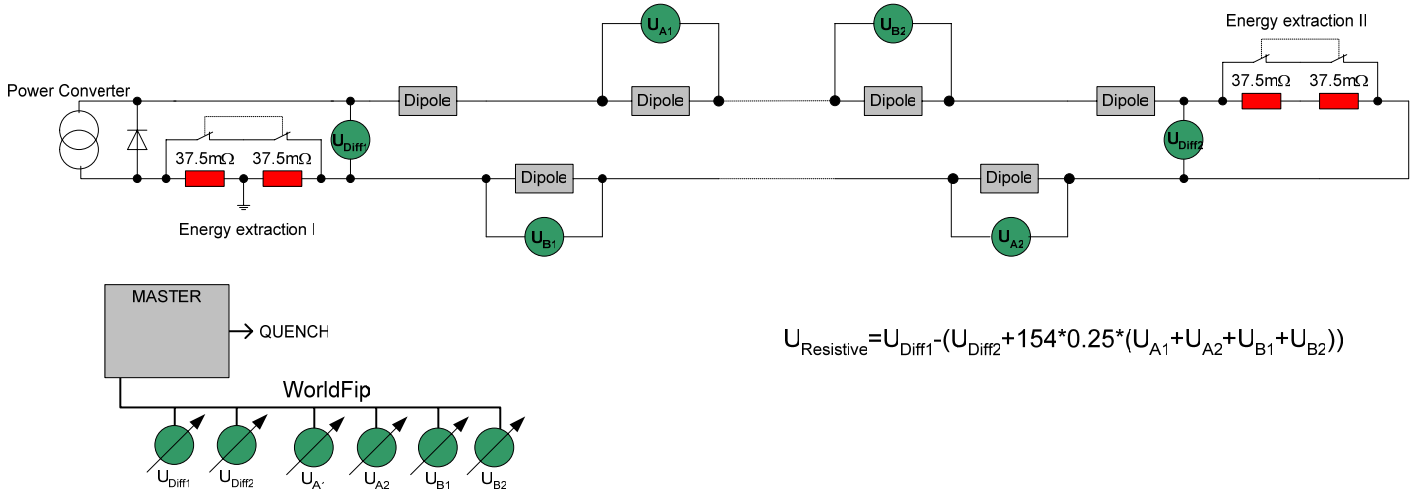


Protection of LHC main magnets: quench heater power supply

- Active protection of superconducting magnets with quench heaters
  - Function based on a thyristor triggered capacitor discharge
  - 4 power supplies per main dipole MB and 2 per lattice quadrupole MQ
  - 6200 units in LHC
  - Integrated together with the quench detection electronics into protection racks to be installed underneath the main dipoles
- Extensive R& D program
  - Component lifetime (Aluminium electrolytic capacitors)
  - Radiation tolerance (main concern: thyristors)
  - Electromagnetic susceptibility



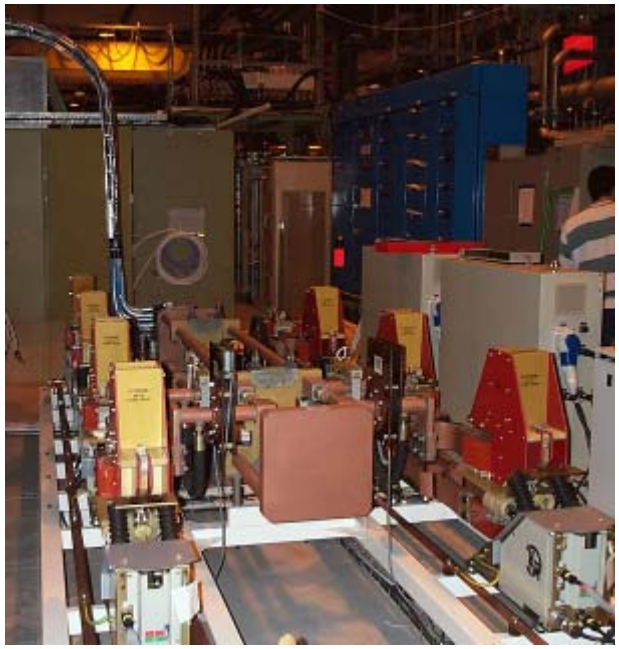
- Digital protection system for 13 kA main busbars (RB, RQF and RQD circuits)
  - Fieldbus controlled voltage pickups distributed over one sector
  - Dedicated fieldbus network operating in real time mode
  - System ensures protection during ramp and coasting
  - Master device in even point calculates resistive voltage (detection threshold = 1 V)



$$U_{Resistive}=U_{Diff1}-(U_{Diff2}+154*0.25*(U_{A1}+U_{A2}+U_{B1}+U_{B2}))$$

Energy Extraction Systems

- 13 kA systems for main circuits RB, RQF and RQD (32 facilities in total)
  - The main dipole circuit has energy extraction systems in the odd and even points, the main quadrupole circuits only in the even points
- 600 A systems for corrector circuit families MCS, MCD, MO, MQS, MQT, MQTL and MS (202 systems in total)
- Both systems based on electro-mechanical DC circuit breakers, specifically designed for the purpose
  - Built-in high redundancy using series and parallel connected current paths (see LHC design report vol. 1, p 273)
  - While a back-up switch is providing enhanced reliability and security in the 600 A energy extraction systems, selected firing of quench heaters in case of a failure of the 13 kA systems.



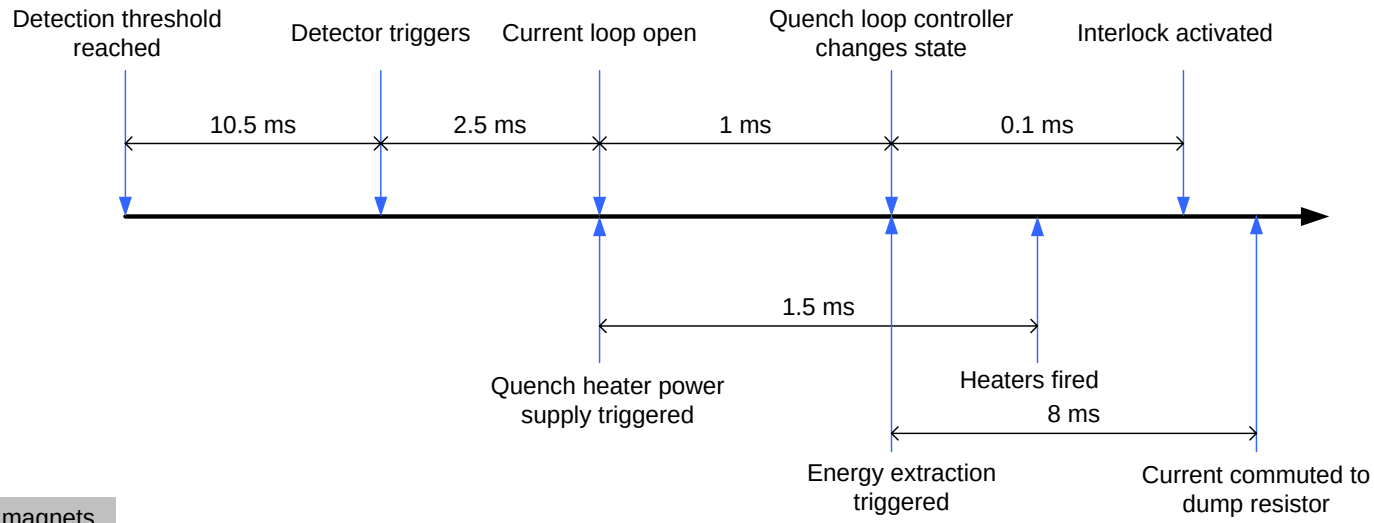
Digital protection systems

- Fast DSP based systems for the protection of corrector and insertion region magnets (including superconducting busbars) and the inner triplets
- High precision system with low detection threshold (U_{TH} = 3 mV) for HTS current leads
- Both systems integrated into so-called Global Protection Units
  - Simultaneous and independent protection of up to 4 superconducting circuits
  - Units control and trigger associated quench heater power supplies

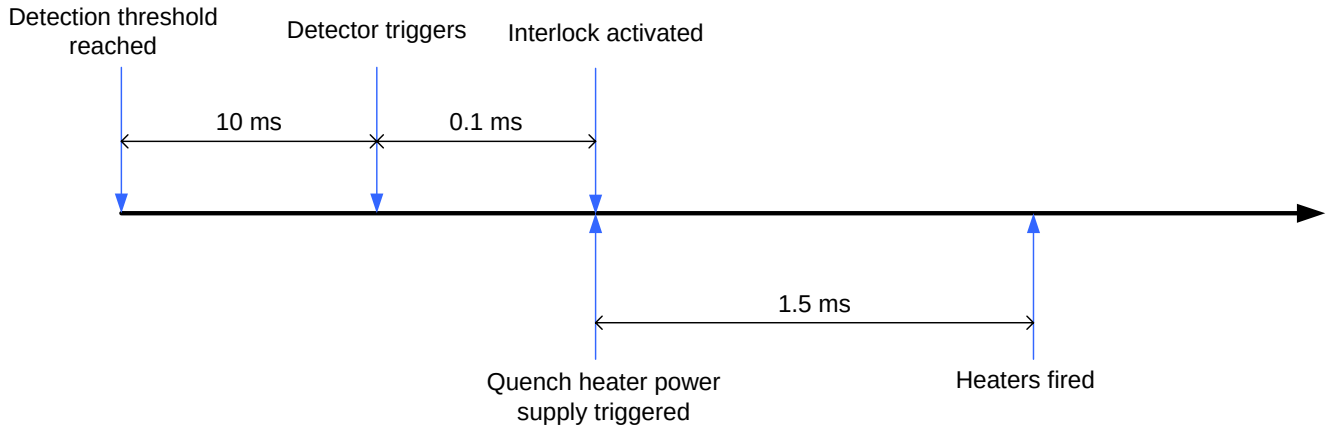
Type A Global Protection Unit for up to 4 corrector magnet circuits. The unit is attached to dedicated 600 A current sensors.

Quench detection time scales

MB and MQ

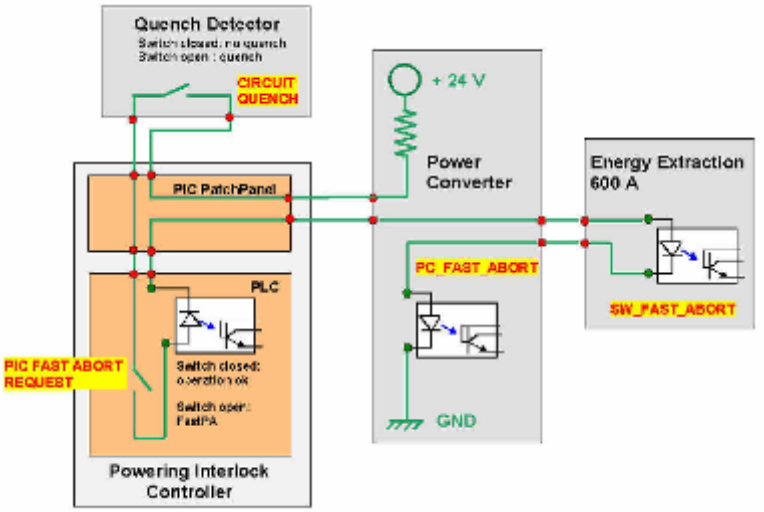


Insertion region magnets and inner triplets



Interface to the Machine Interlock System

- Hardwired interlock loops for the Power Abort signal
  - Current loops linking the power converter, the powering interlock controller and the quench protection system
  - Long current loops internal to the quench protection system for the main circuits (linking the odd and even points)
- Software link for the transmission of the Power Permit signal



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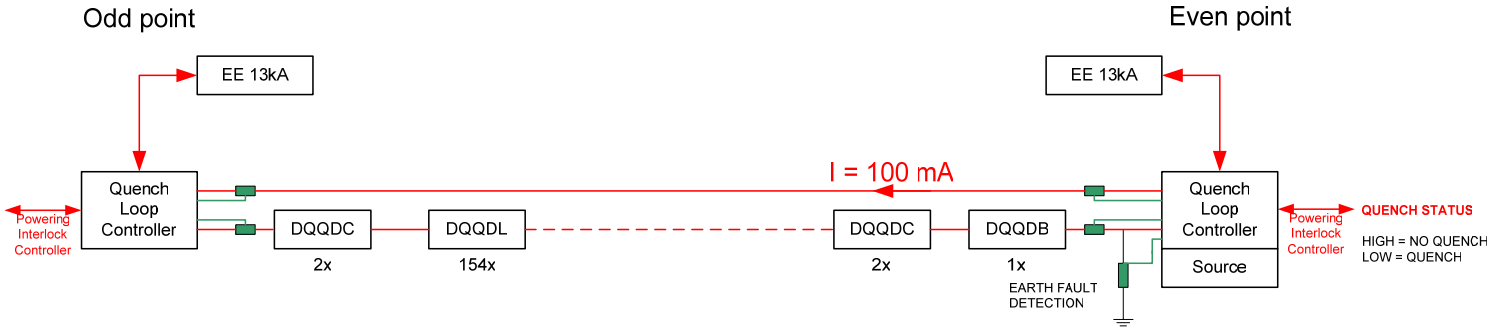
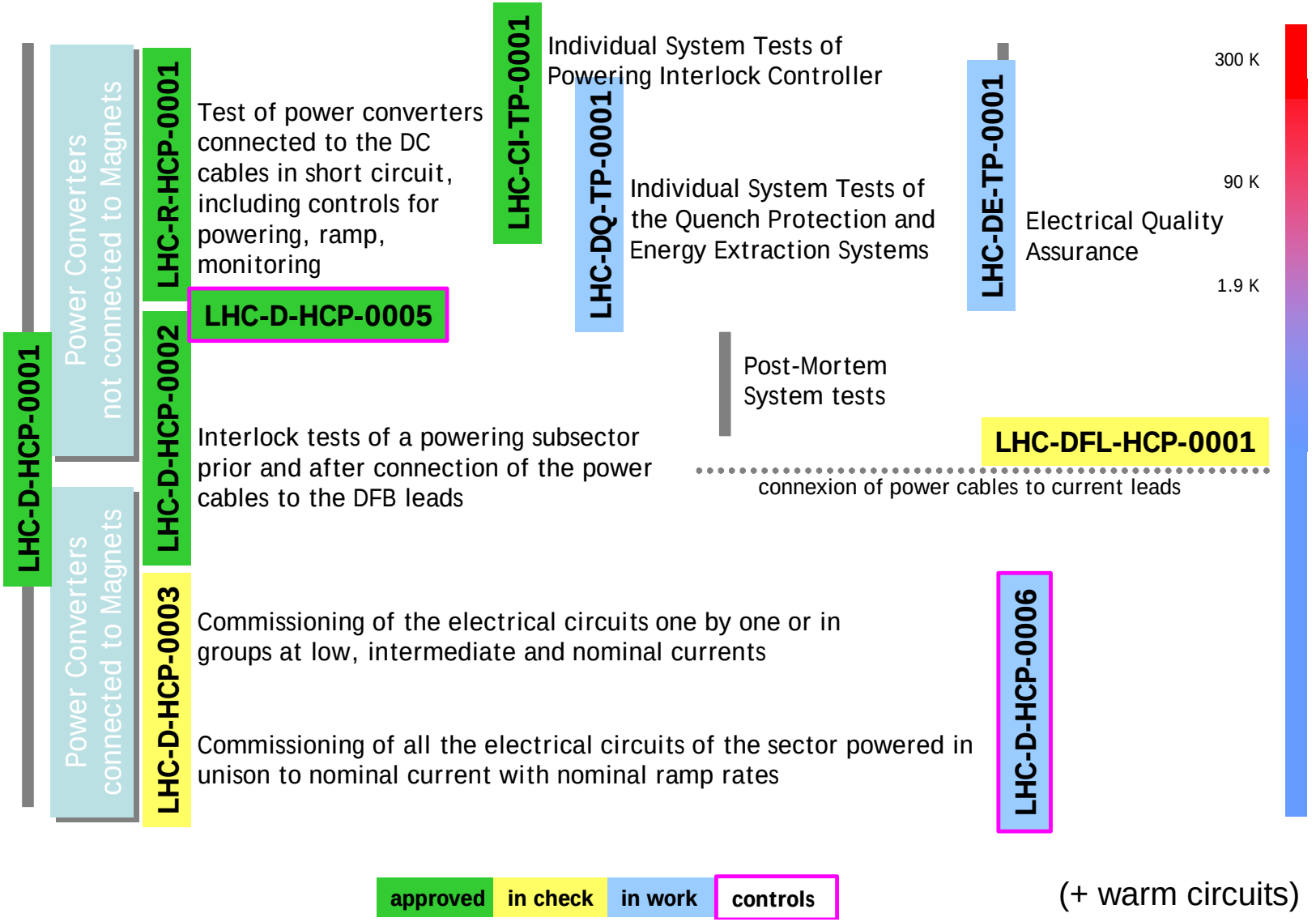


Hardware commissioning strategies

documentation: superconducting electrical circuits



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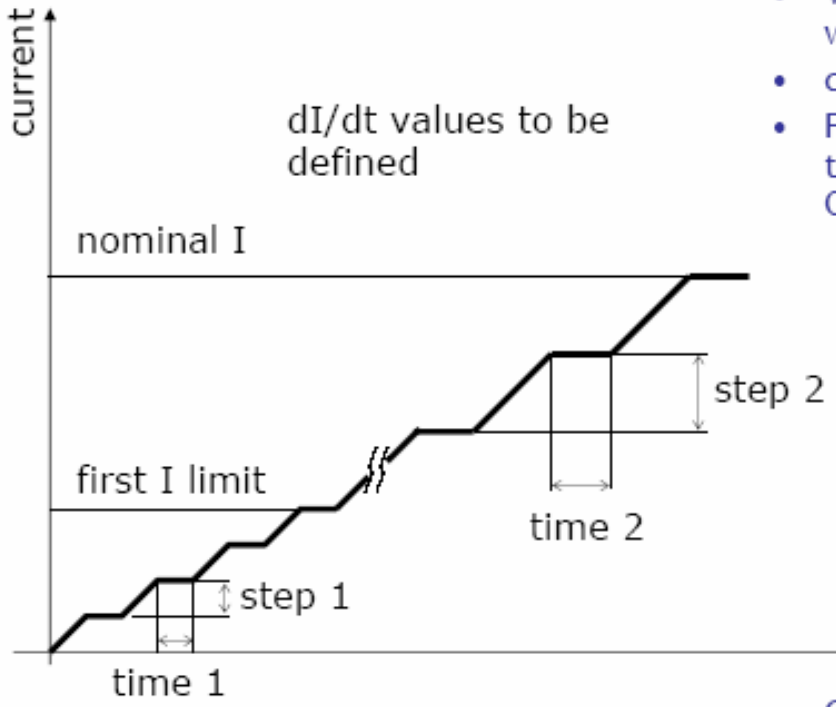
Powering strategies

This is to be applied ONLY the first time the circuit sees a new current level through it

powering strategy



- Verified, automated procedures will be carried out
- dI/dt are fixed (in principle)
- First ramps are used to initialize the L(I) tables for the numerical QD
- Commissioning of several circuits at the same time (group commissioning)
- Which circuits first?

Félix R.M., SACEC 041104

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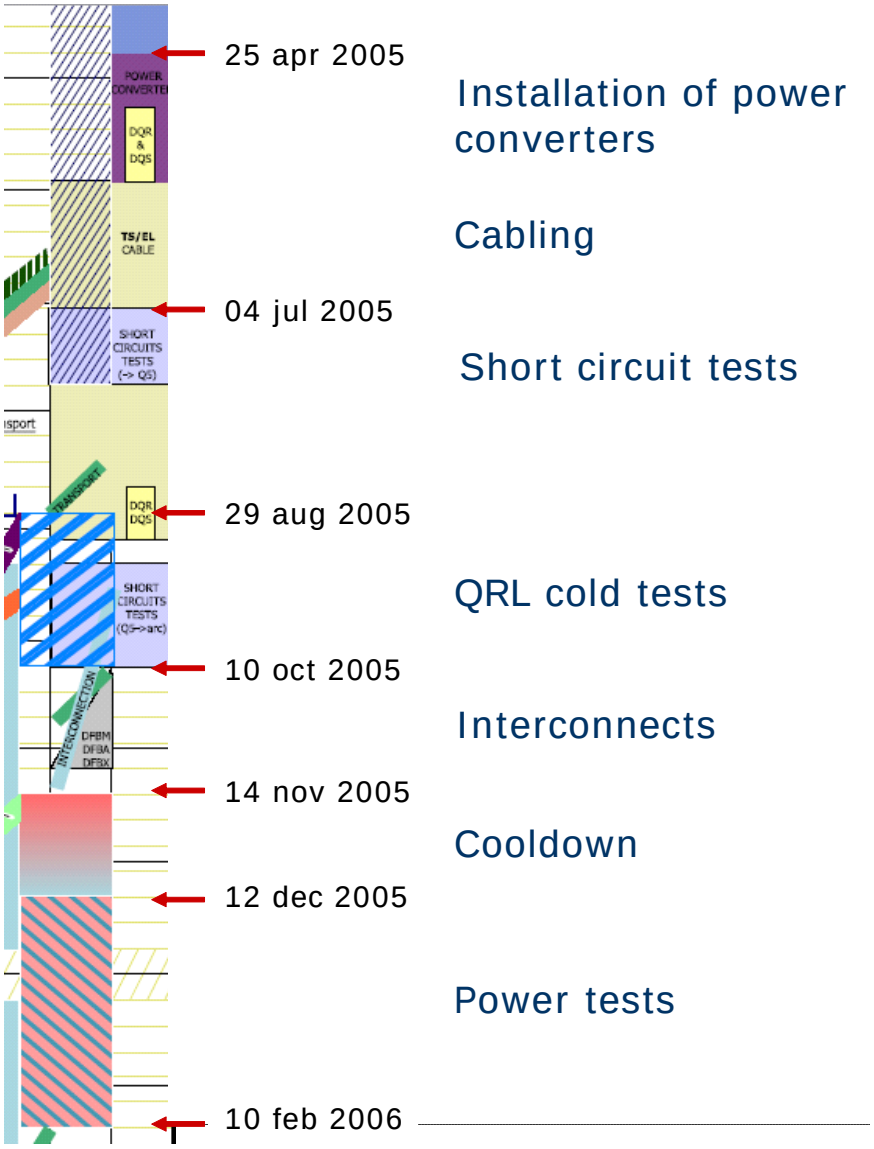
Hardware commissioning roadmap

Roadmap



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