# General considerations for the crowbar design of the HL-LHC circuits

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On behalf of WP6B Warm Powering

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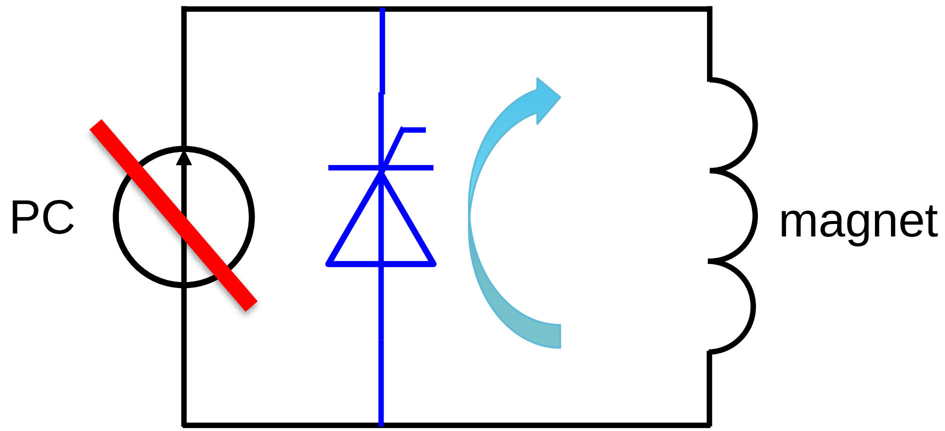
# *Power converter crowbar*

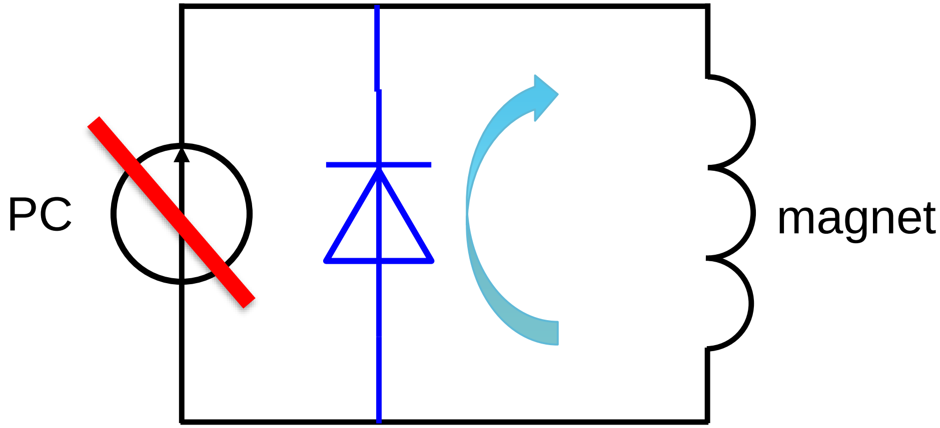
# Power converter crowbar

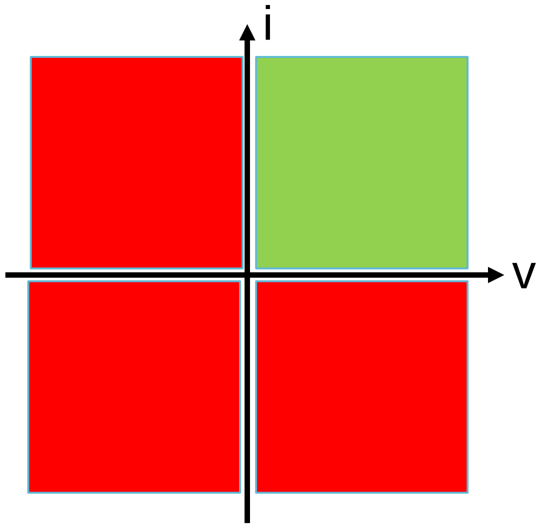
- The main function of the crowbar is to protect the electrical circuit (PC, DC cables and magnet) by giving a path for current in case of PC trip



# Power converter crowbar

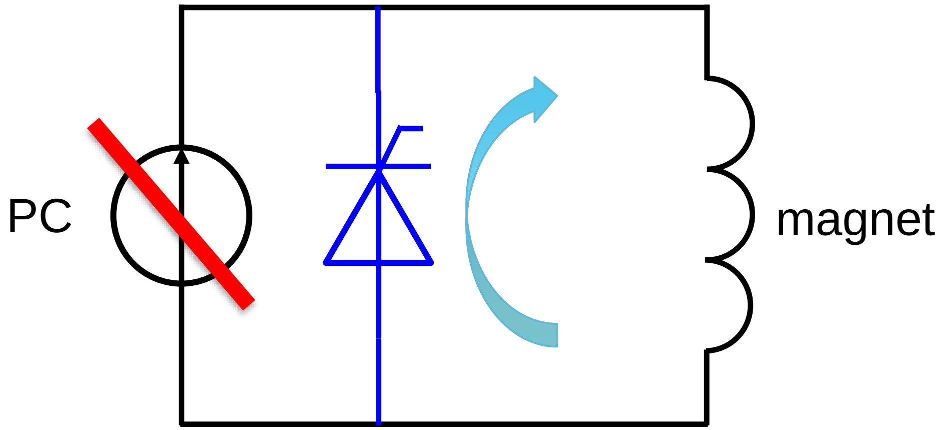
- Different types of crowbar
  - 1Q power converter => Diode

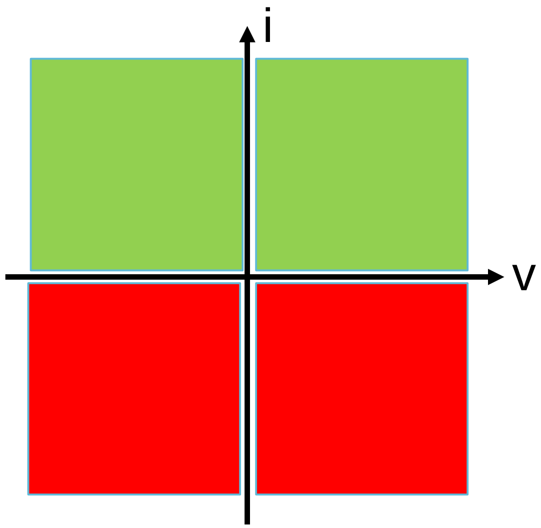


# Power converter crowbar

- Different types of crowbar
  - 1Q power converter => Diode
  - 2Q (bipolar in V) power converter => Thyristor



# Power converter crowbar

- Different types of crowbar
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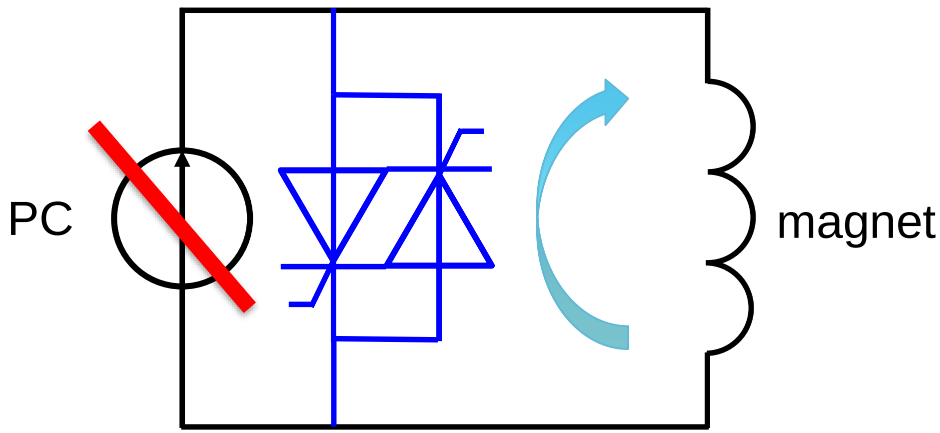
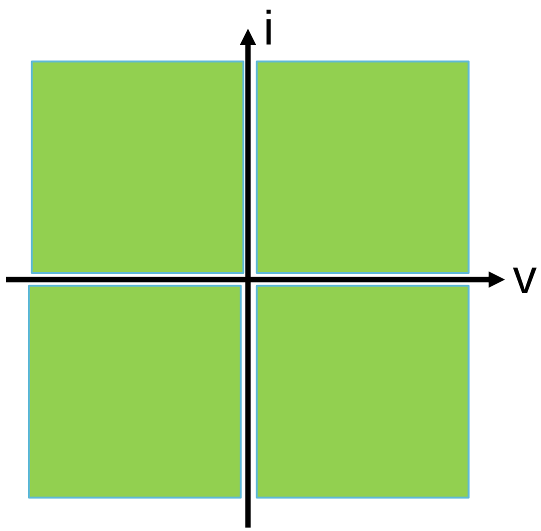
  - 2Q (bipolar in V) power converter => Thyristor
  - 4Q power converter => 2 thyristors back2back



# Power converter crowbar

- The main parameters for the crowbar design:
  - $V_{peak}$, $I_{peak}$ and $P_{peak}$ are defined by the power converter
  - Energy and current decay ($\tau$) are defined by the magnet
  - Crowbar has to be natural air cooled (in case of water fault)
  - Auto-maintain (not need of external energy to maintain the crowbar ON)

# Power converter crowbar

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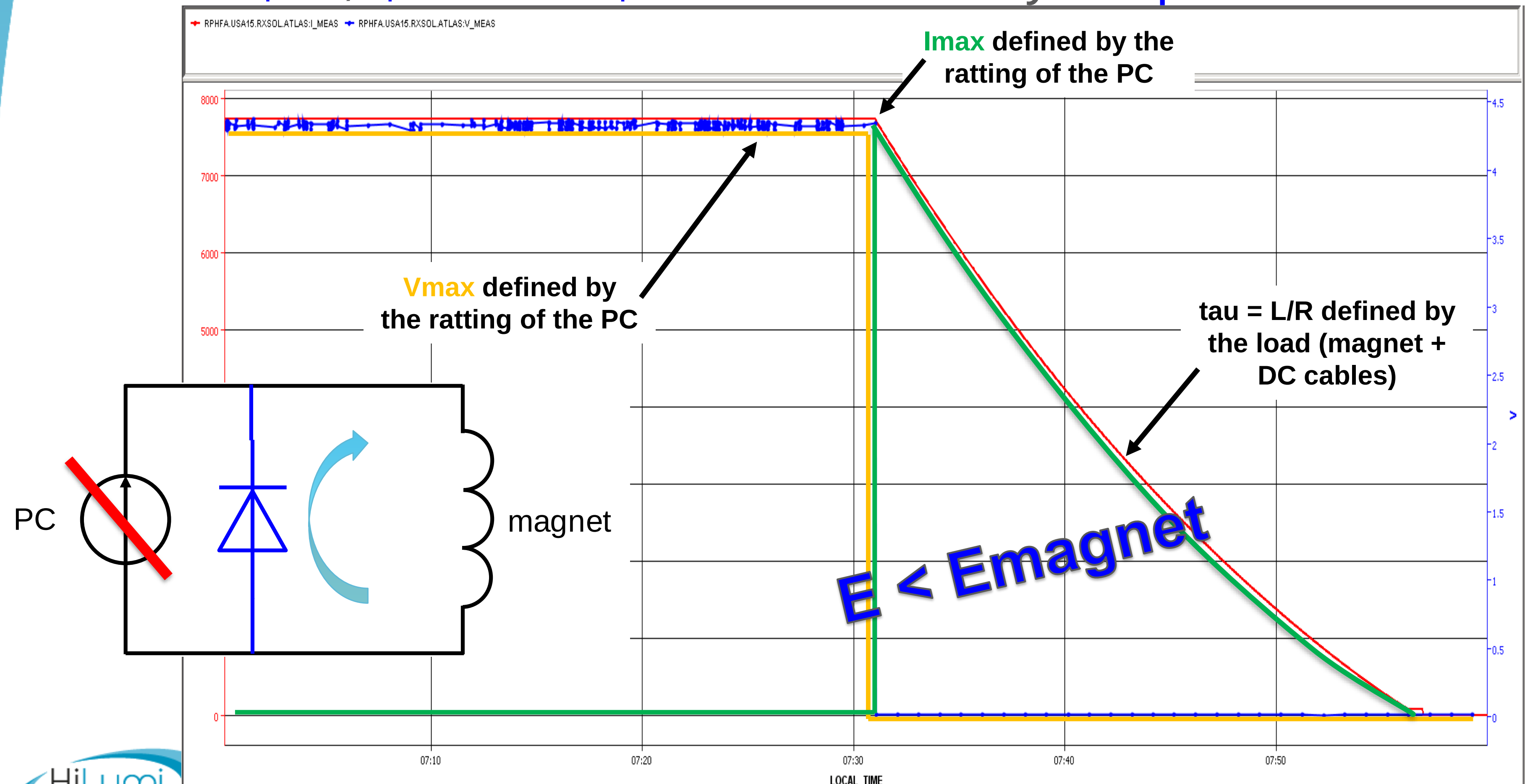
  - $V_{peak}$, $I_{peak}$ and $P_{peak}$ are defined by the power



# *Crowbar for superconducting circuits*

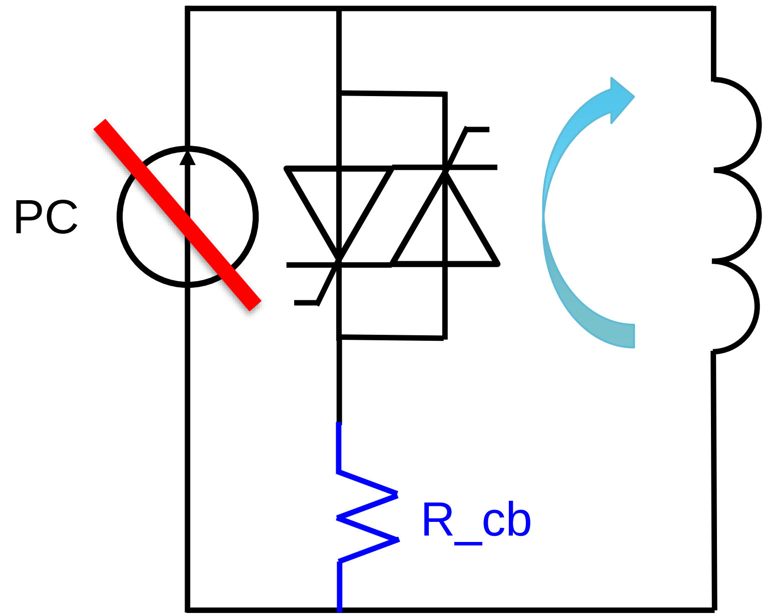
# Crowbar for superconducting circuits

- Superconducting circuits can have
  - High current (>1 kA) and high inductance (>1 H)
  - Low resistance (<10 m$\Omega$, only DC cables)
- main part of the magnet energy is dissipated in the crowbar

**Series resistor can be added to reduce the constraints (E and $\tau$) for the crowbar (diodes or thyristors)**

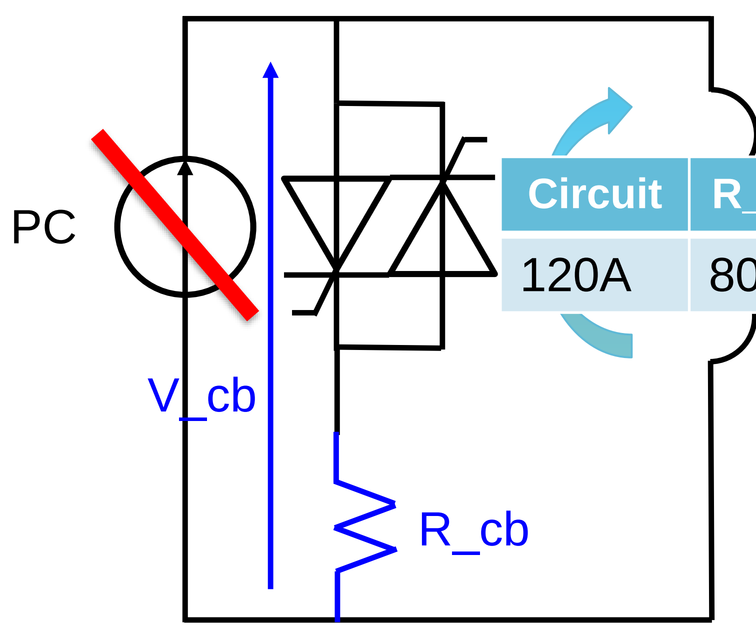
# Crowbar for superconducting circuits

- Crowbar resistor
  - The series resistor absorbs a part of magnet energy and reduces the time constant of the discharge (positive point for the magnet)



# Crowbar for superconducting circuits

- Crowbar resistor
  - Example: Crowbar resistor is used for the LHC 120A power converters.




| Circuit | R_cb [mR] | V_cb [V] | V_pc [V] |
|---|---|---|---|
| 120A | 80 | 9.6 | 10 |

**V_cb < V_pc**

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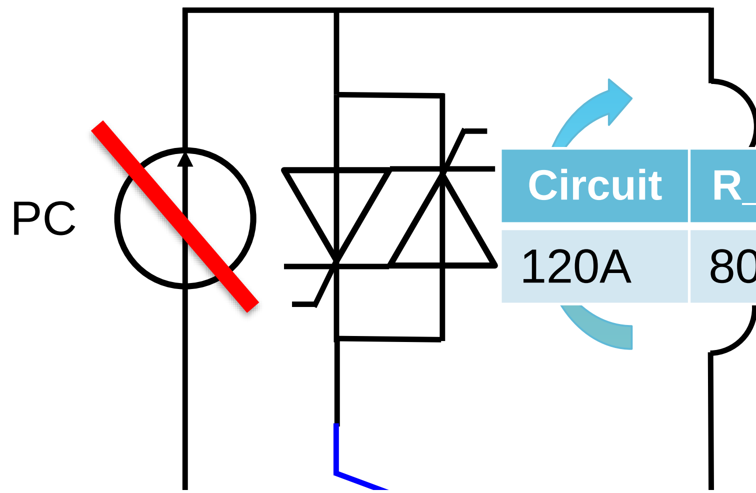


| Circuit | R_cb [mR] | V_cb [V] | V_pc [V] |
|---|---|---|---|
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**V_cb < V_pc**

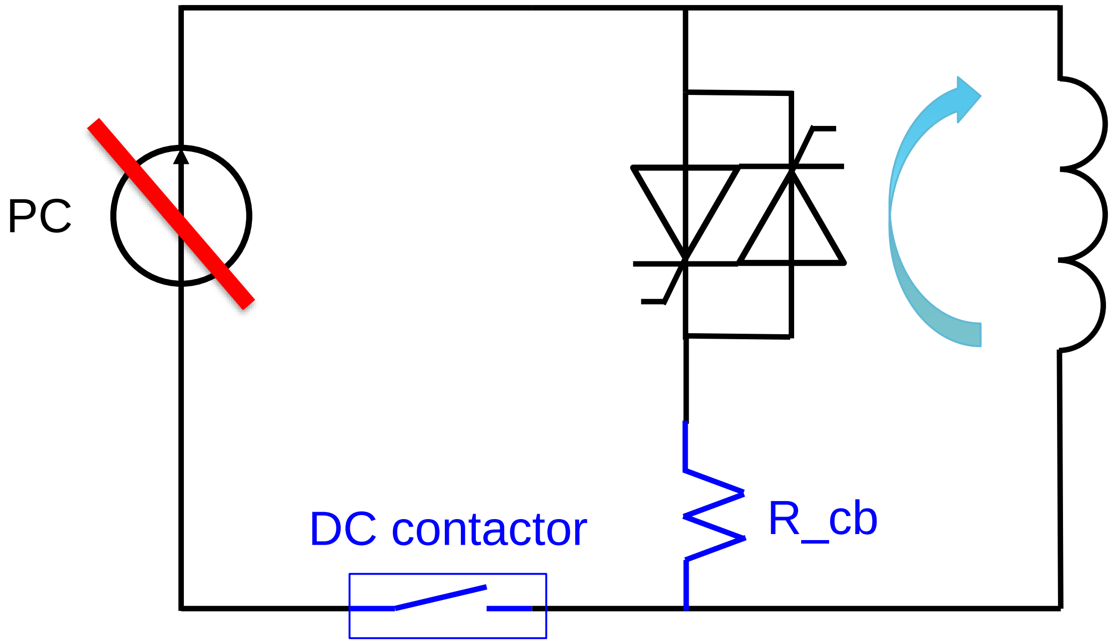
**Can we go above nominal voltage of the power converter ?**

# Crowbar for superconducting circuits

- Crowbar resistor
  - The [600A/10V] PCs power superconducting circuits with huge inductance and huge time constant (eg. RU circuits with 4.8 H and 1000 s)
  - The crowbar resistor is 50 mΩ and the voltage across the PC during the discharge is 30V.
    - Constraints for the power converter (over voltage)
    - Constraints for the superconducting circuit (di/dt > nominal di/dt)
    - Constraints for the QDS (protection by global voltage)

# Crowbar for superconducting circuits

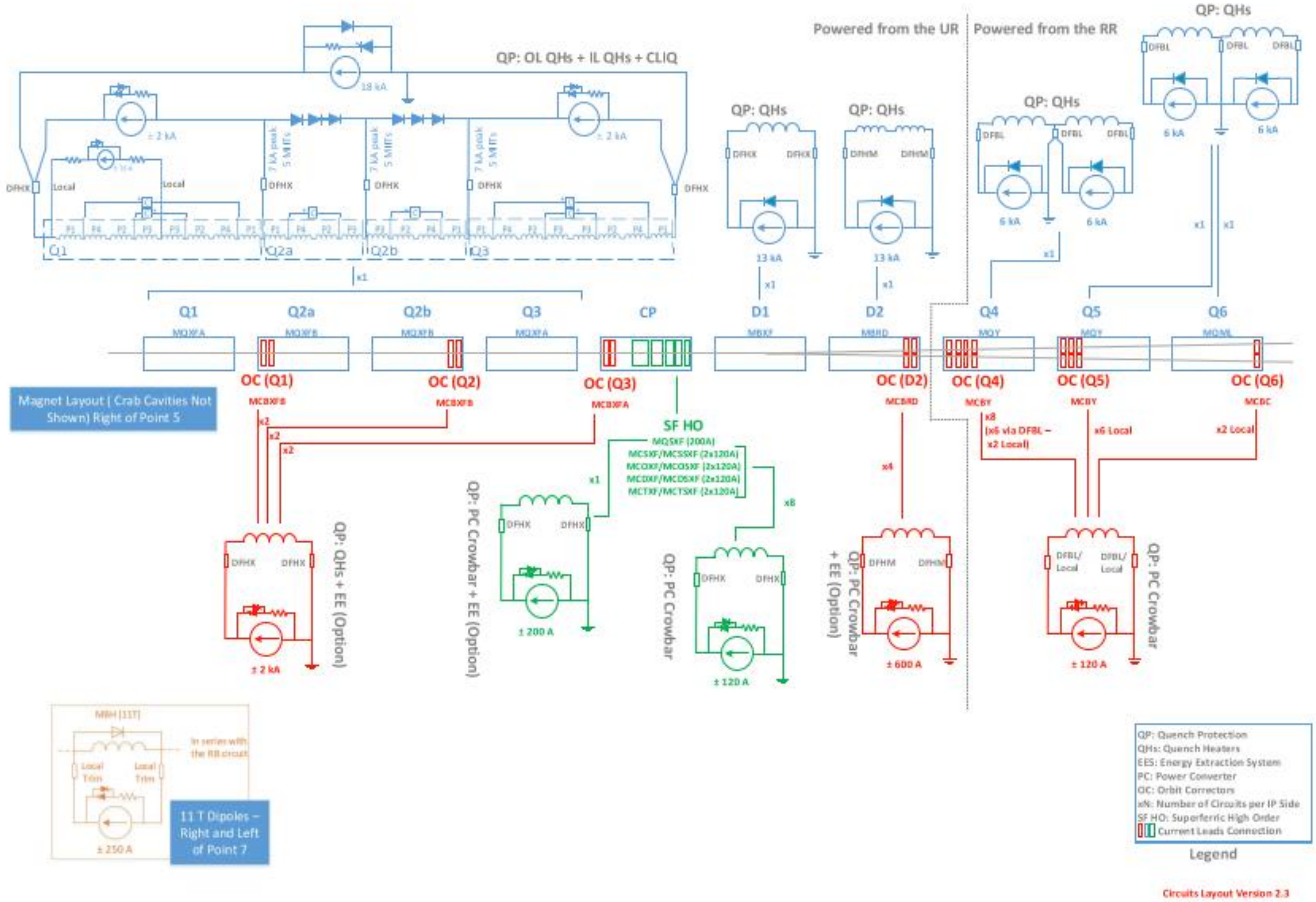
- SC busbar can be protected by the Crowbar ?
  - Risk to bypass the crowbar in case of PC short circuit
  - DC contactor added in series with the PC to increase the safety level of the discharge system



# *Crowbar for HL-LHC circuits*

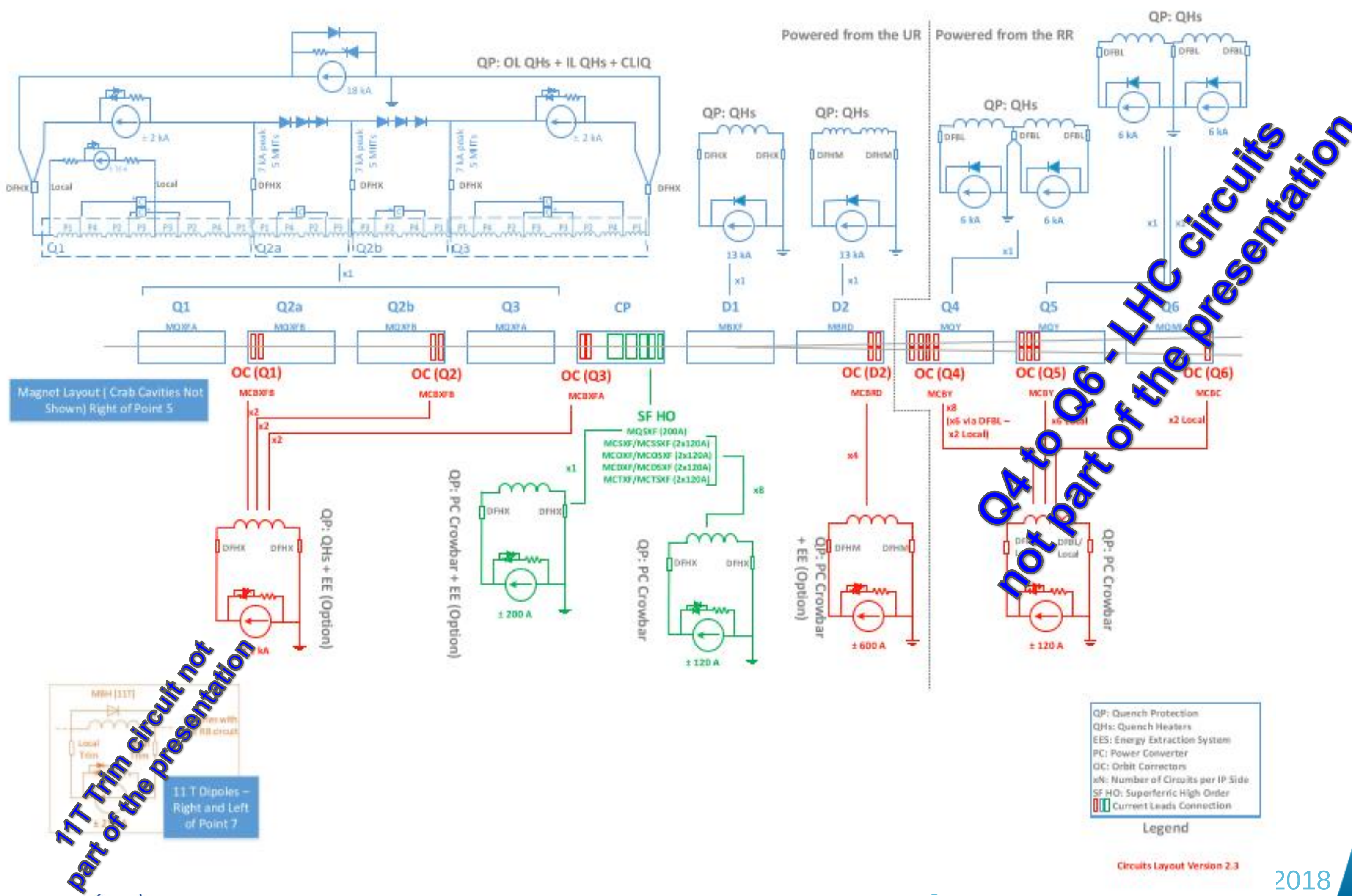
# Crowbar for HL-LHC circuits

- HL-LHC circuits



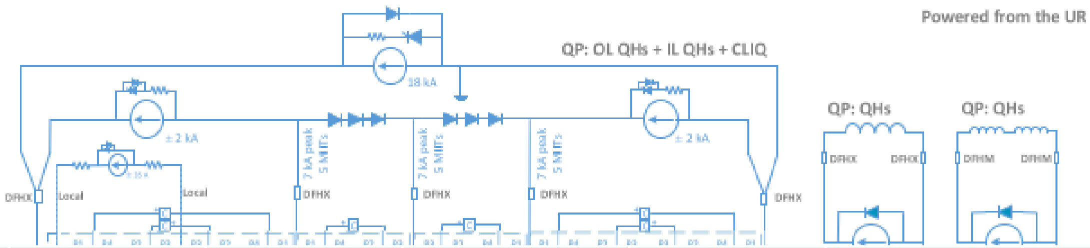
# Crowbar for HL-LHC circuits

- HL-LHC circuits



# Crowbar for HL-LHC circuits

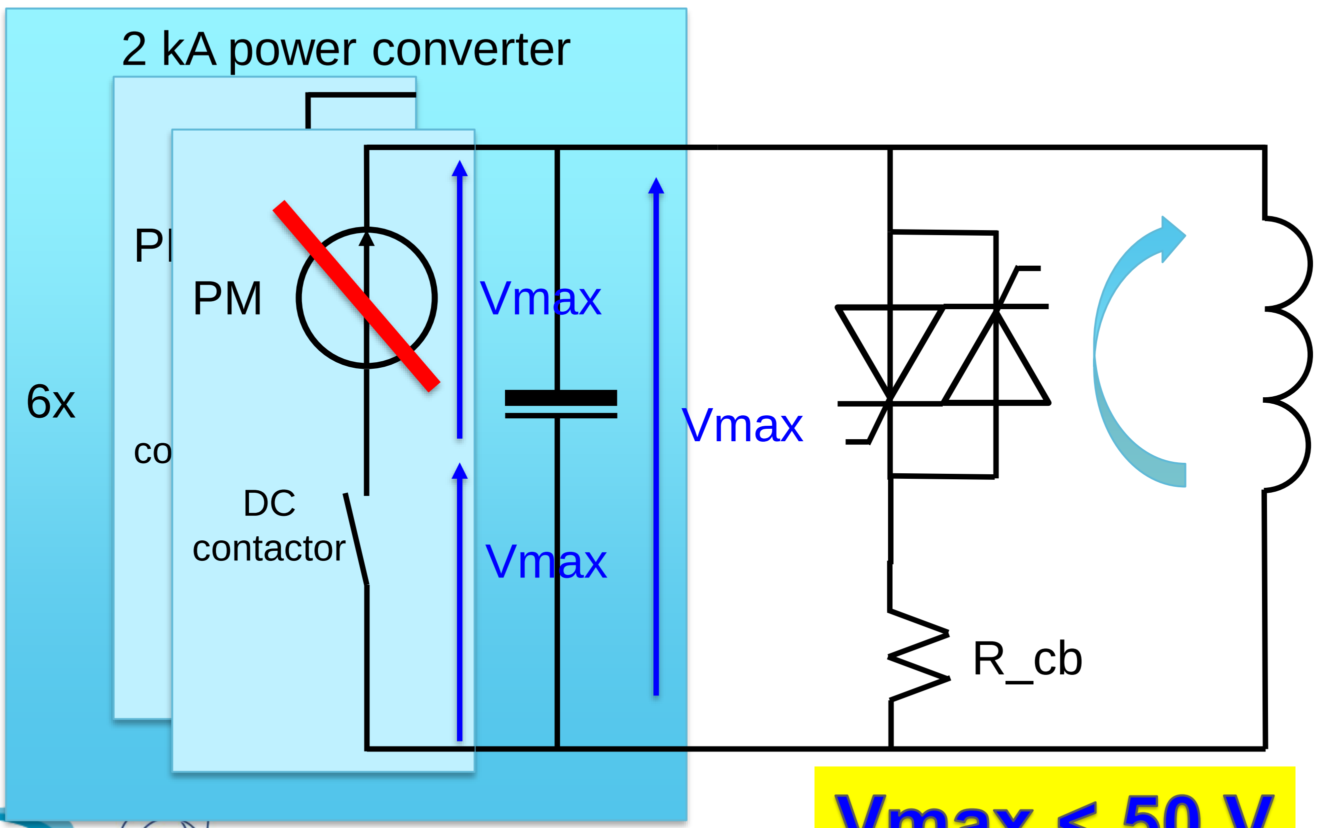
- HL-LHC circuits




| Circuit | I_pc [A] | V_pc [V] | Quadrant | Magnet | Crowbar | R_cb [mΩ] | V_cb [V] | Based on |
|---|---|---|---|---|---|---|---|---|
| 120A | 120 | 10 | 4Q | CP | Thy_B2B | 80 | 9.6 | LHC |
| 200A | 200 | 10 | 4Q | CP | Thy_B2B | 50 | 10 | LHC R2E |
| 600A | 600 | 10 | 4Q | OC(D2) | Thy_B2B | 50 | 30 | LHC R2E |
| 2kA | 2’000 | 10 | 4Q | OC(Q1toQ3) | Thy_B2B | 7 | 14 | New |
| 13kA | 13’000 | 8 | 1Q | D1/D2 | Diode | - | 0 | LHC R2E |
| IT Main | 18’000 | 10 | 2Q | Q1toQ3 | Thy | 0.5 | 9 | New |
| IT Trim | 2’000 | 10 | 4Q | Q1/Q3 | Thy_B2B | 7 | 14 | New |
| IT kmod | 35 | 8 | 4Q | Q1a | Thy_B2B | ?? | ?? | LHC |

# Crowbar for HL-LHC circuits

- 2kA power converter
  - Redundant power converter with 6 sub-PC in parallel




**Vmax < 50 V**

# Crowbar for HL-LHC circuits

- 2kA power converter
  - 2 cases to take in account to design the 2 kA crowbar resistor
    - Power converters for OC(Q1toQ3)
    - Power converters tor IT TRIM

| PC | Over Current [A] | R_cb [mΩ] |
|---|---|---|
| OC(Q1toQ3) | 2’000 | < 25 |
| TRIM(Q1&Q3) | 7’000 | < 7 |

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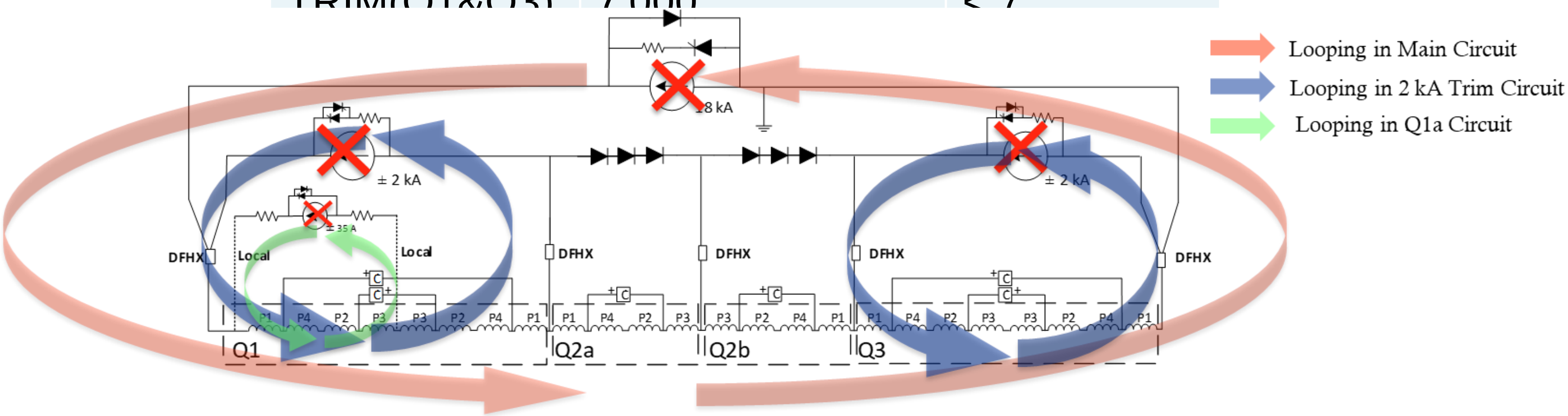
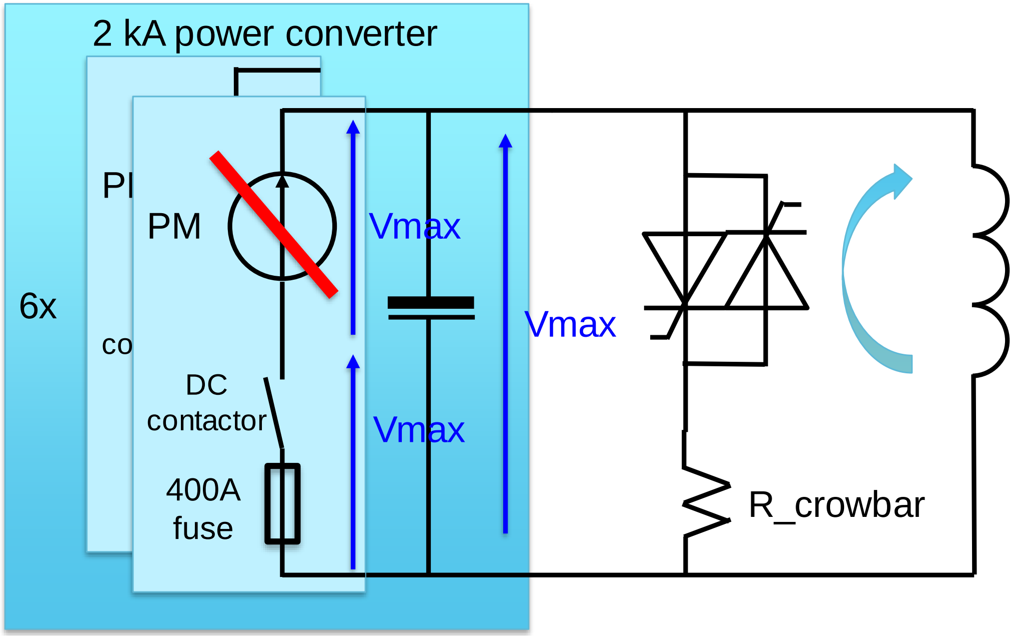


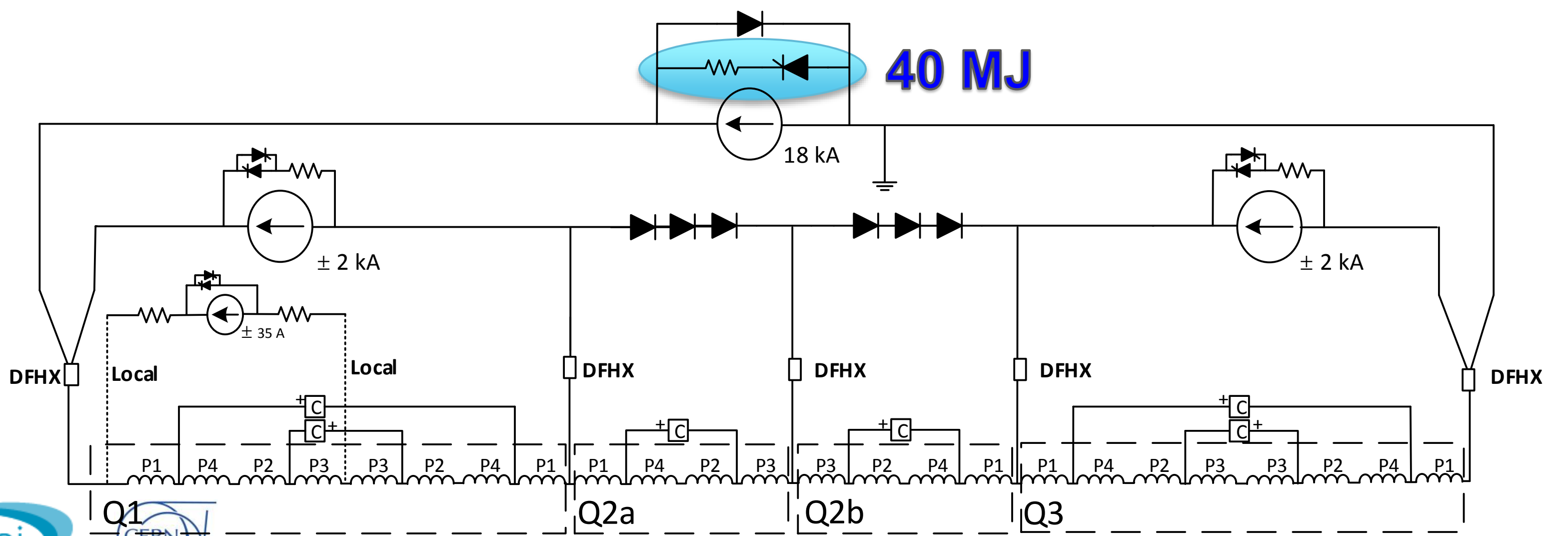
# Crowbar for HL-LHC circuits

- 2kA power converter
  - If the crowbar is critical for the protection of the SC busbar then 400A fuses can be added in series with the DC contactor of each sub converter



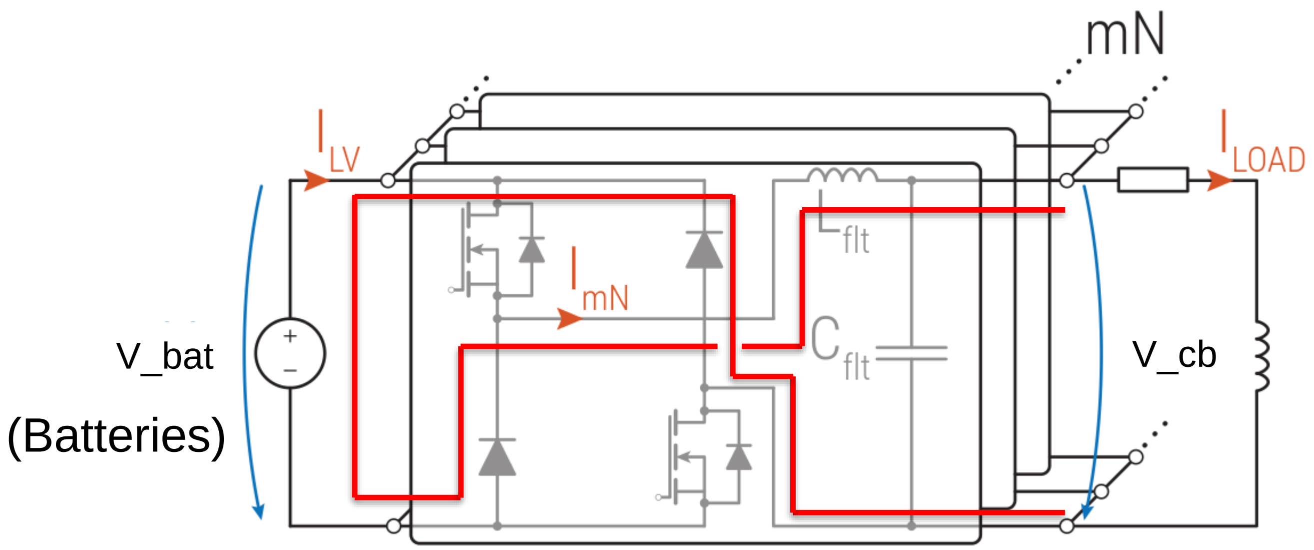
# Crowbar for HL-LHC circuits

- 18kA power converter
  - Huge energy stored in the circuit (Q1, Q2a, Q2b and Q3
  - No DC cables
    - Time constant > 500 s
    - Full magnet energy dissipated in the crowbar



# Crowbar for HL-LHC circuits

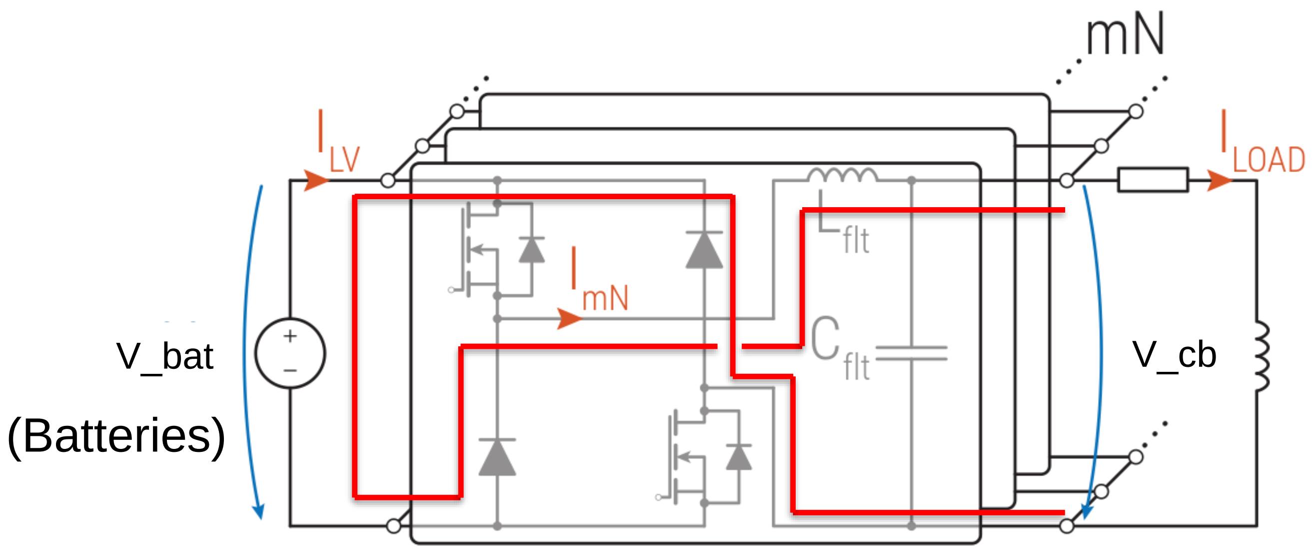
- 18kA power converter
  - N sub-converters with M sub-module in parallel
  - Diodes of the output stage in parallel with the crowbar




**V_cb < V_bat (24 V)**
**$\tau$ > 250 s**

# Crowbar for HL-LHC circuits

- 18kA power converter
  - If V_cb > 24 V is requested then external 18 kA EE system is mandatory



# *Conclusion*

# Conclusion

- The function of the crowbar is to protect electrical circuit (PC, DC cables and magnet) by giving a path for current when the power converter is OFF (normal or fault off)
- Resistor in series with the crowbar can be added to reduce the time constant of the discharge but in this case the V_cb shall be close to the V_pc
- For high discharge voltage, EE system must be used

***Thank you for your attention…***