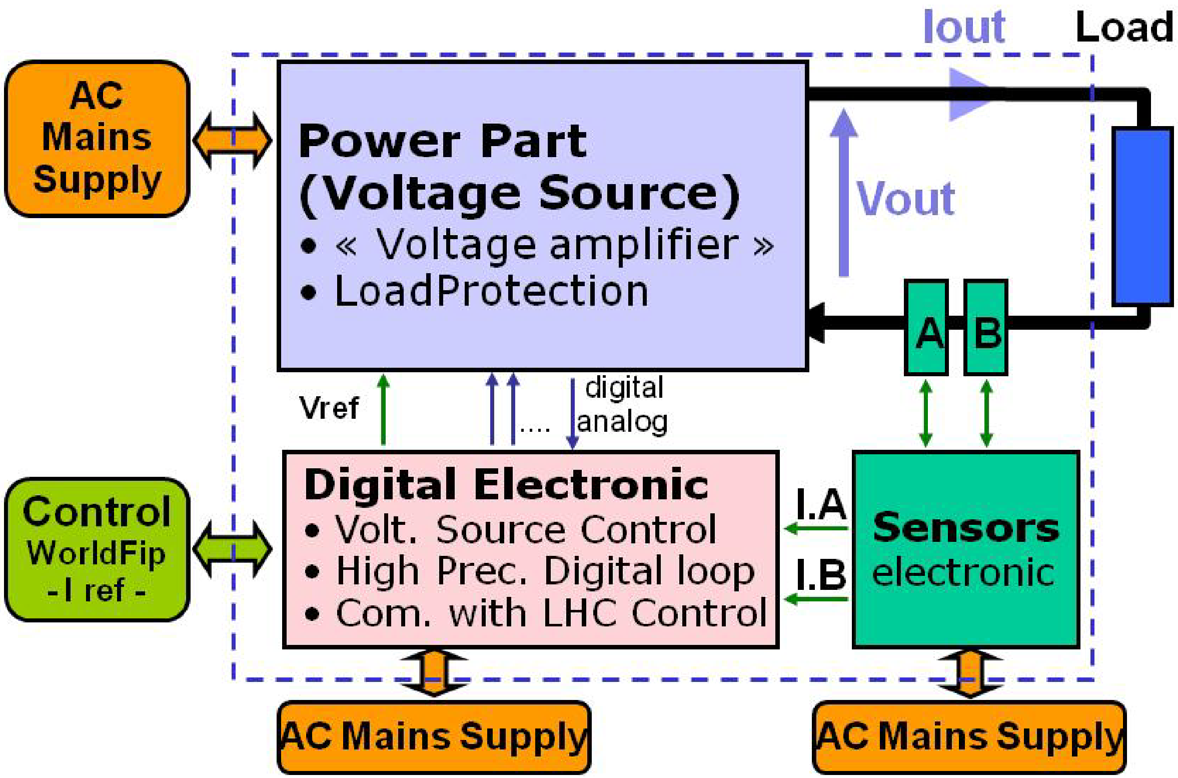
Power Converters implications for CLIC machine protection

Power converter Architecture

- **Power conversion unit**
- **Digital control unit**
- **High precision measurement Sensor unit**



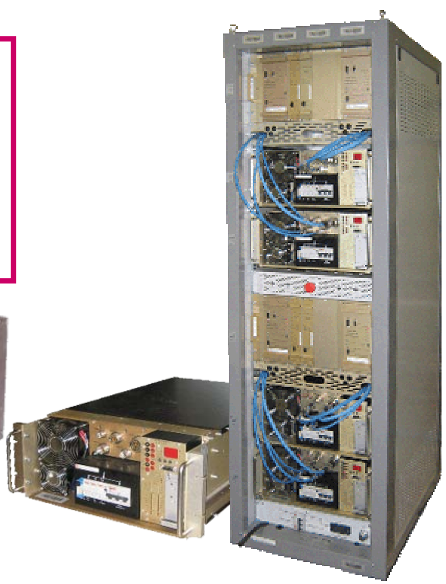
Typical LHC Power converters (1/2)

LHC60A-08V
4-Quadrant

730 Units
CERN Design

LHC120A-10V
4-Quadrant

300 Units
CERN Design



LHC600A-10V
4-Quadrant

400 Units
EEI-CIRTEM

LHC600A-40V
4-Quadrant

40 Units
Transtechnik

Typical LHC Power converters (2/2)

LHC13kA-180V
2-Quadrant

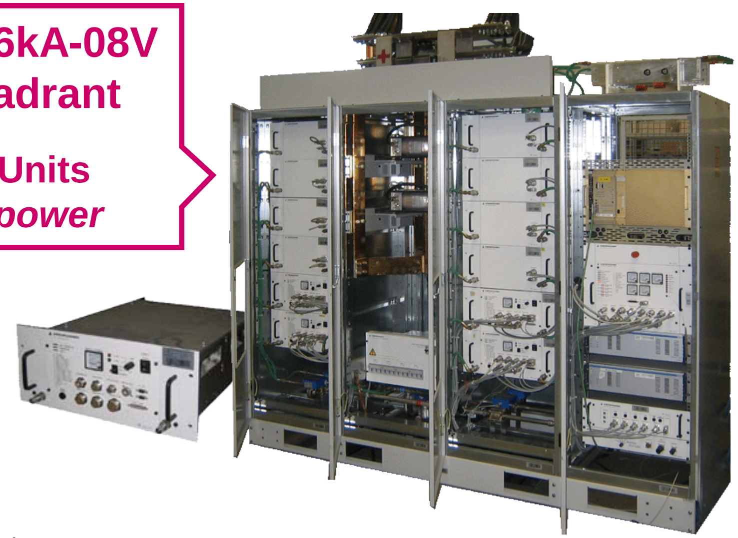
8 Units
CERN Design

LHC13kA-18V
1-Quadrant

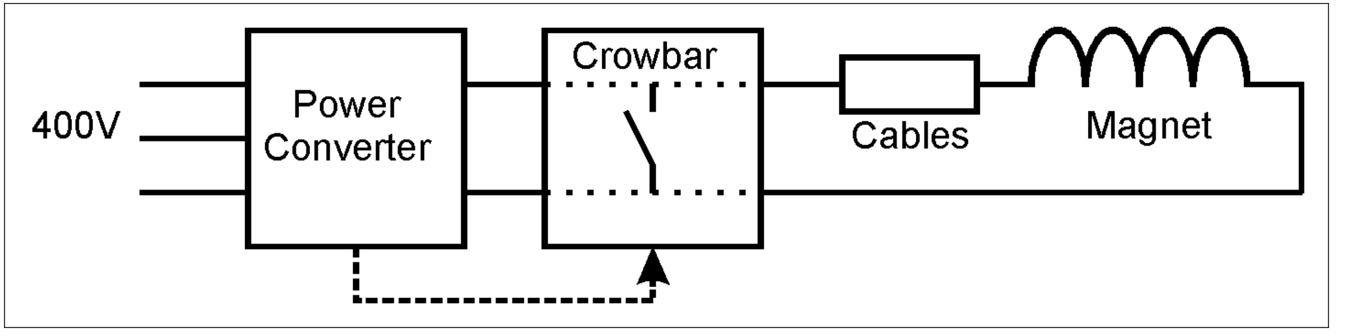
16 Units
Transtechnik

LHC4..6kA-08V
1-Quadrant

200 Units
Kempower



Power converter failure (1/2)

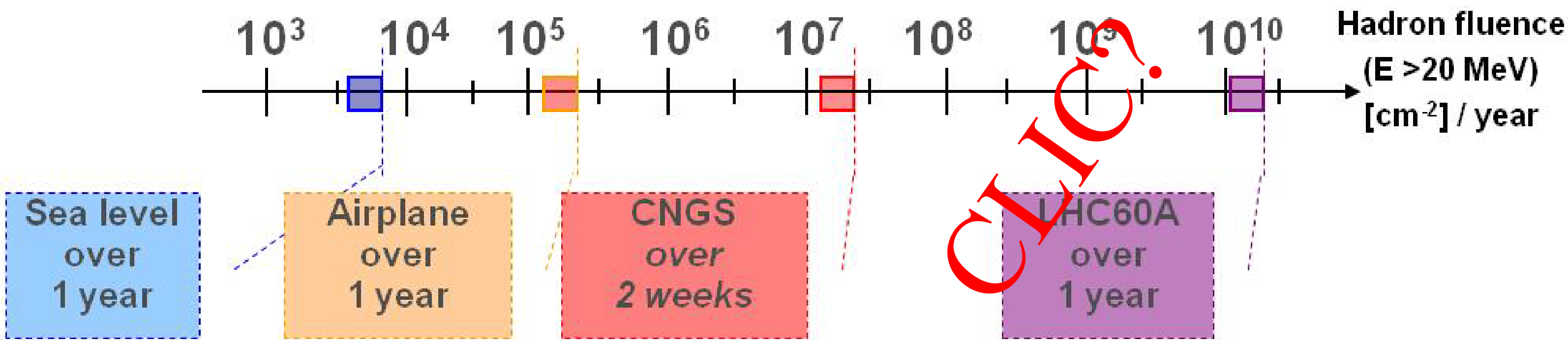


- **Any power device may fail open or shorted.**
- **The converter usually fails**
  - **Open in case of internal control failure**
  - **Shorted in case of a power semi-conducteur failure**
- **An additional external passive crowbar is then needed to ensure a failure in shorted mode.**

Power converter failure (2/2)

- **Even if some converter failures may take seconds to be detected, a small current error may be quickly detected and processed.**

- **Any SEU or SEL may lead to a severe failure (including permanent damage) on the power side of the converter.**



CLIC power converters

- **Drive beam quadrupoles:**
  - 41’400 magnets (75W to 750W) powered in groups of 4 or 8.
  - 5’000 to 10’000 power converters
- **Main beam quadrupoles:**
  - 308 x 1kW magnets (125A/0.06Ω/10mH)
  - 1’268 x 2kW magnets (125A/?/?)
  - 954 x 3kW magnets (125A/?/?)
  - 1’462 x 4kW magnets (125A/0.26Ω/43mH)
  - 4’000 power converters needed
- **Main beam correctors (proposed by Hermann Schmickler)**
  - 3’992 x 50W magnets and power converters

Note: damping rings, transport lines, turn around not yet considered

CLIC Machine protection

- **CLIC is essentially a continuous beam line. The duration of the main pulse is 150ns. It will be impossible to intervene once the main beam or the drive beam goes astray due to in flight errors.**

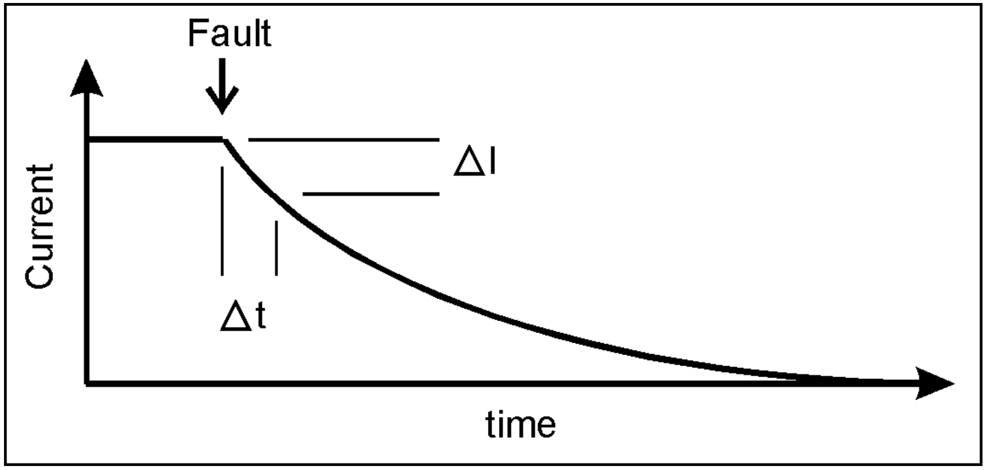
- **Once the beam permit has been delivered, power converters and their magnets must have a large enough inertia to deliver the required current during the next 2ms.**

Current inertia principles

in case of failure, a passive current inertia can be provided if:

- **A free wheeling path exists to the current.**
- **The energy stored in the magnet or in the power converter free wheeling path is large enough to compensate the losses in the magnet and in the cables during the requested safety time.**
- **Long cables will drastically reduce the inertia capability and increase the power converter ratings.**

Magnets with large time constant

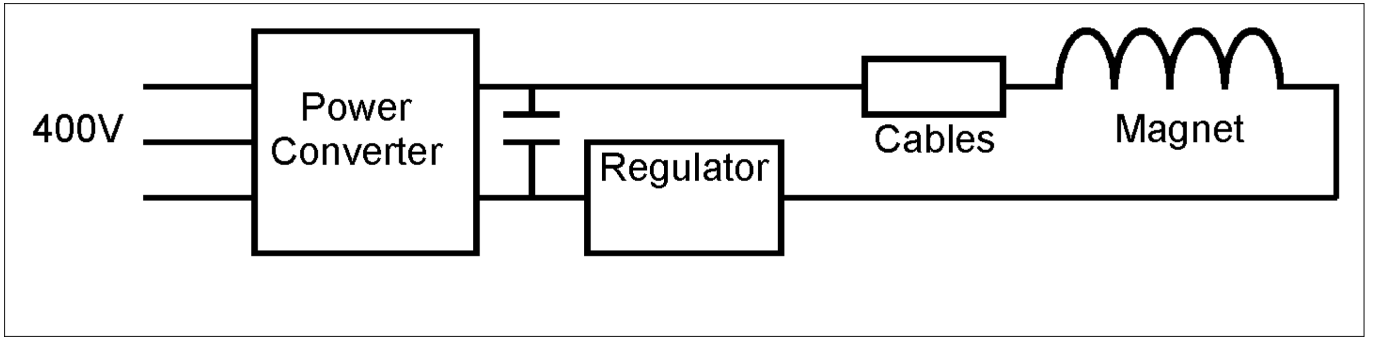


Small current variation:

$\Delta I/I = \Delta t \cdot R/L$

- **Current inertia depends on the magnet inductance and on the cables resistance. (i.e time constant)**
- **As an example, Type 4 main beam quadrupoles (125A/0.26Ω/43mH) would keep magnet current in a 1.2% window during 2ms, without any connection cable!**

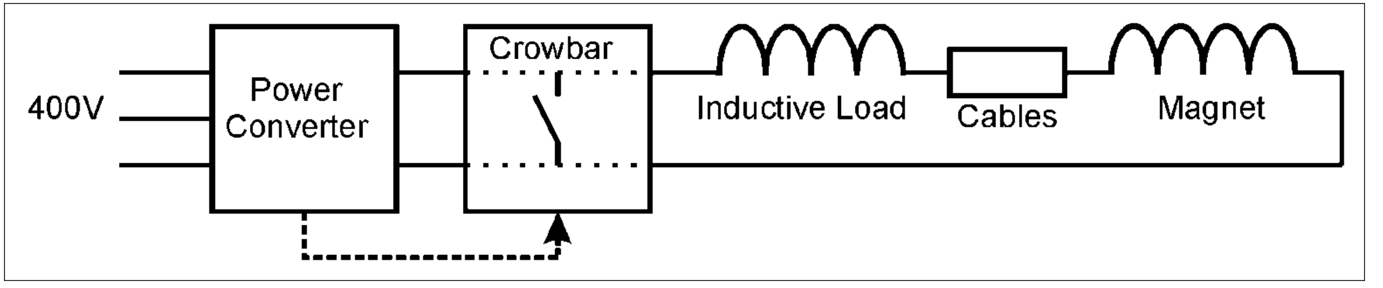
Magnets with small time constant (1/2)



1st possibility: Capacitive energy storage

- **The power converter MUST fail in open mode (fuse?).**
- **The Regulator (when present) must fail in shorted mode.**
- **The capacitor bank provides the energy to compensate the cables losses at a given current during 2ms.**
  - **0.2F needed to maintain 10A on a 1mH/100mΩ load!**

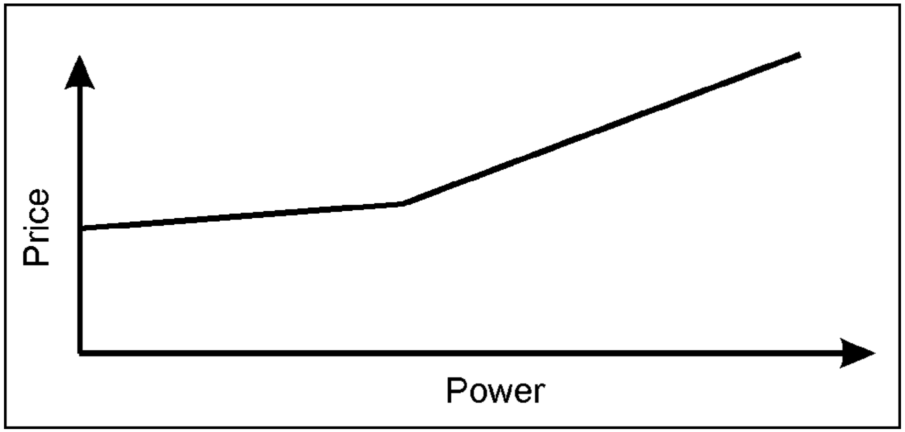
Magnets with small time constant (2/2)



2nd possibility: Inductive energy storage

- **Load L/R >> Magnet L/R**
- **The power converter must fail in shorted mode.**
- **The additional Inductive load provides the energy to compensate the cables losses at a given current during 2ms.**
- **Magnetic coupling management of these additionnal inductive load may be tricky.**

Low power converters costs



- **Initial offset due to remote control, auxiliary supplies, faults supervision,…**
- **Many components must be over-rated while not available for a very low power conversion.**
- **Radiated environment has a significant impact on the power converter cost, depending on strategy applied**

Some possible scenarios

- **Power converter close to the magnets:**
  - **+ Magnet initial inertia is not degraded by long resistive cables**
  - **Power converters have to be rad-hard => significant impact on the power converter cost.**

- **Power converter in a radiation safe area:**
  - **+ Standard power converters can be used**
  - **- Long cables are needed (up to 2 times 400m)**
  - **- Increase of the power converter ratings to compensate the losses in the cables.**
  - **- Magnet natural inertia is lost. Additional inductors may be needed to keep the current in the requested safety window.**

Conclusion

- **The purpose of this presentation is not to provide solutions but to highlight some possible difficulties.**
- **Inertial protection may be achieved in some cases, but may have a significant cost depending on the load characteristic.**
- **Waiting on current final tolerances and all magnets data for further investigation.**
- **A lot of technical choices may have a significant impact on power converter design and cost.**
- **Please contact us…**

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