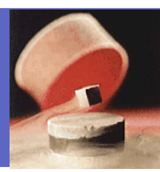
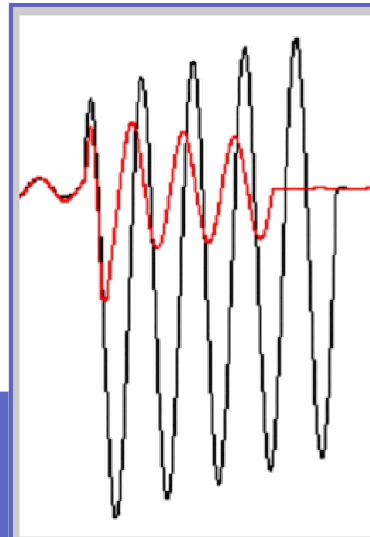
Development at ABB

Superconducting Fault Current Limiter based on Bi-2212





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Developing Superconducting Fault Current Limiter at ABB

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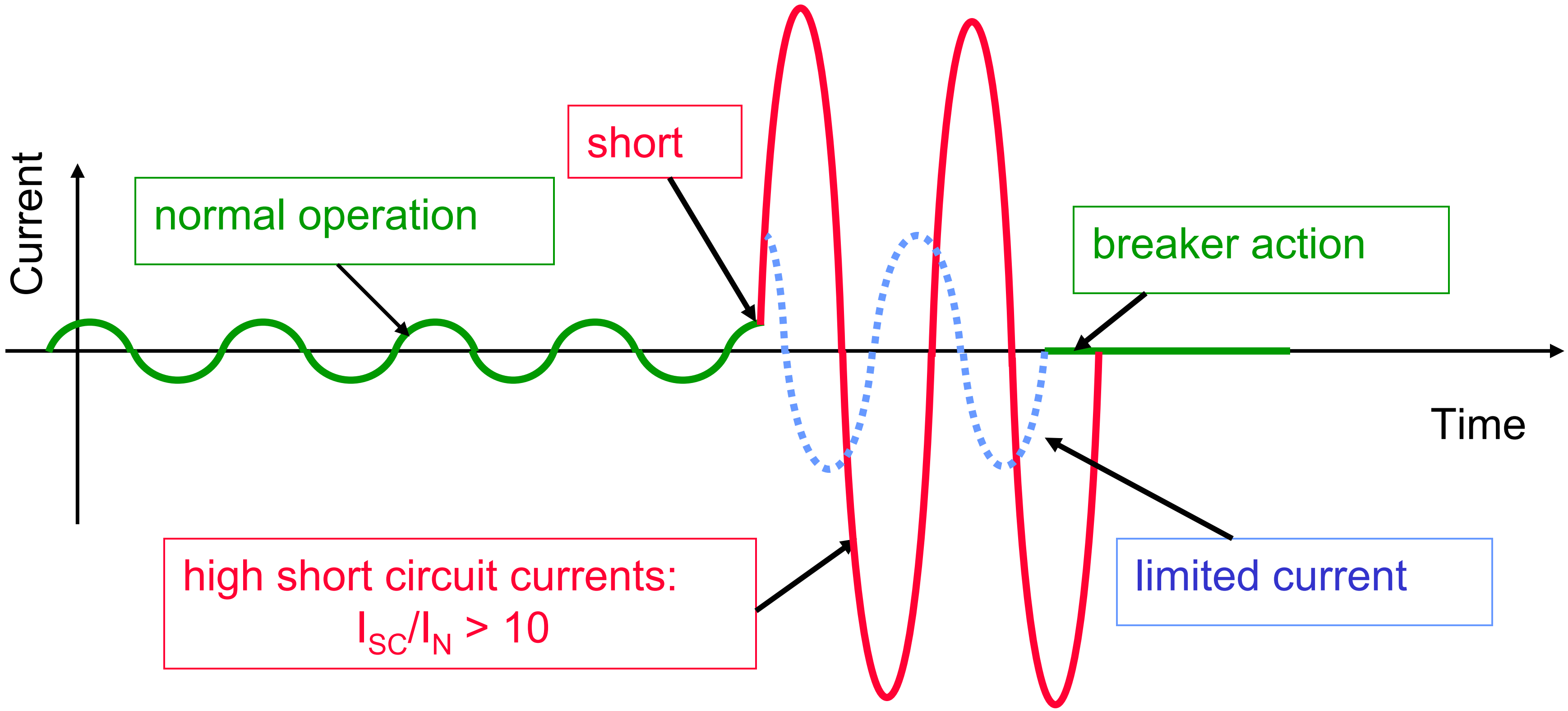
- Introduction
- Basic design aspects
- Materials requirement
- Characterization of Bi-2212 SCFCL component
- Status of development on SCFCL component
- Application
- Conclusions and outlook

昆明，06-2004

Why Current Limiter



1.) high mechanical and thermal stresses until breaker interrupts: $\int \sim I_{sc}^2 \, dt$ => extra costs for reinforcement in transformers, generators, ...

2.) difficult to interrupt => expensive breakers

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Measures for Current Limitation

- Air-coils (reactors)
- Artificially increased reactance in transformers
- Artificial splitting of grids
- Fast breaker (mechanical or electronic)
- Explosive fuse
- LC-Circuits (will be de-tuned in case of a fault)
- PTCs : strong non-linear R(T)
- non-linear resistances: - semiconductor (e.g. diodes)
  - iron core coils
  - **superconductor**

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Status of SCFCL development

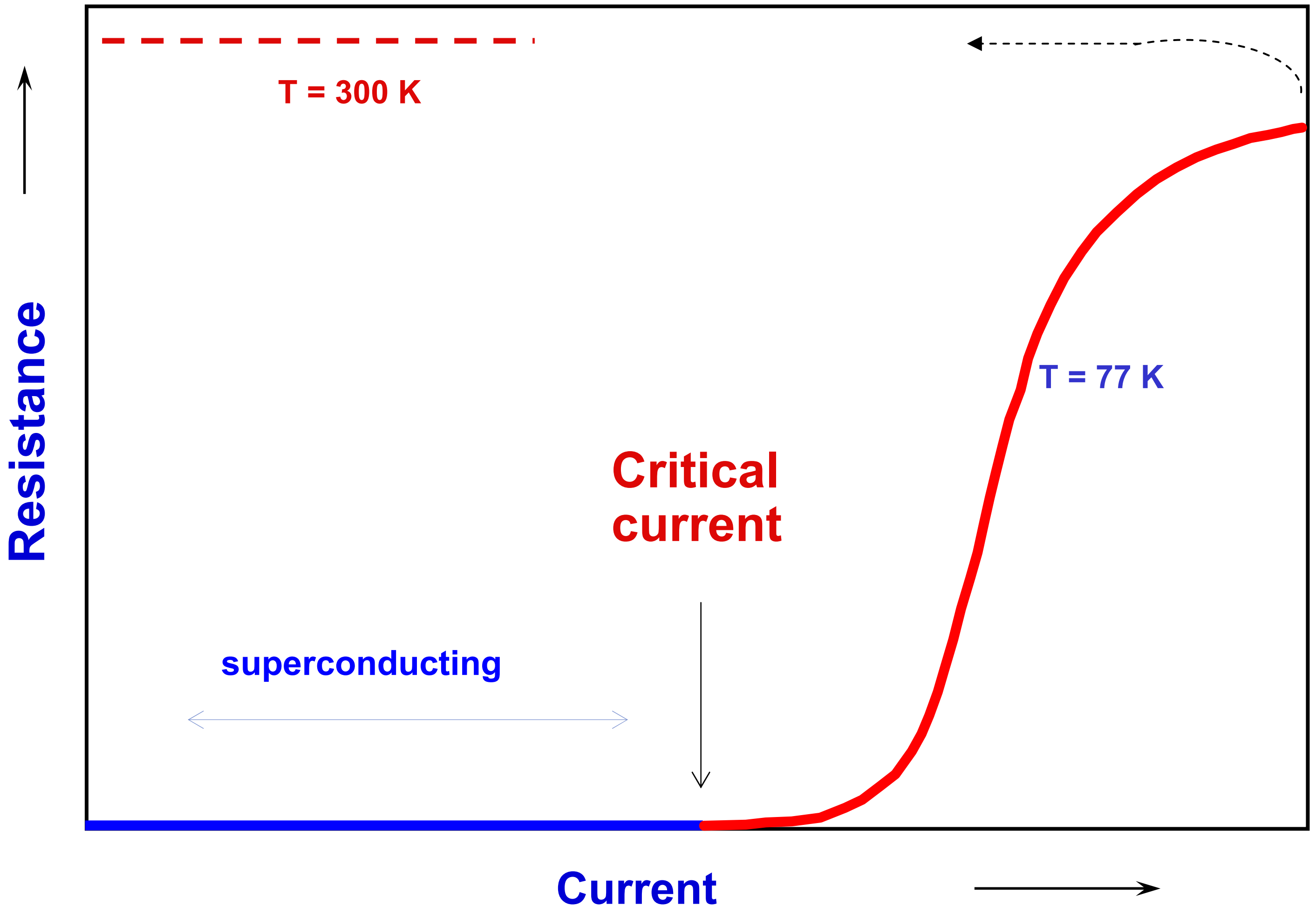
YBCO-coated conductor

- 3 phase 1.2 MVA prototype: **SIEMENS**
  plates (10 x 10 cm), Au bypass

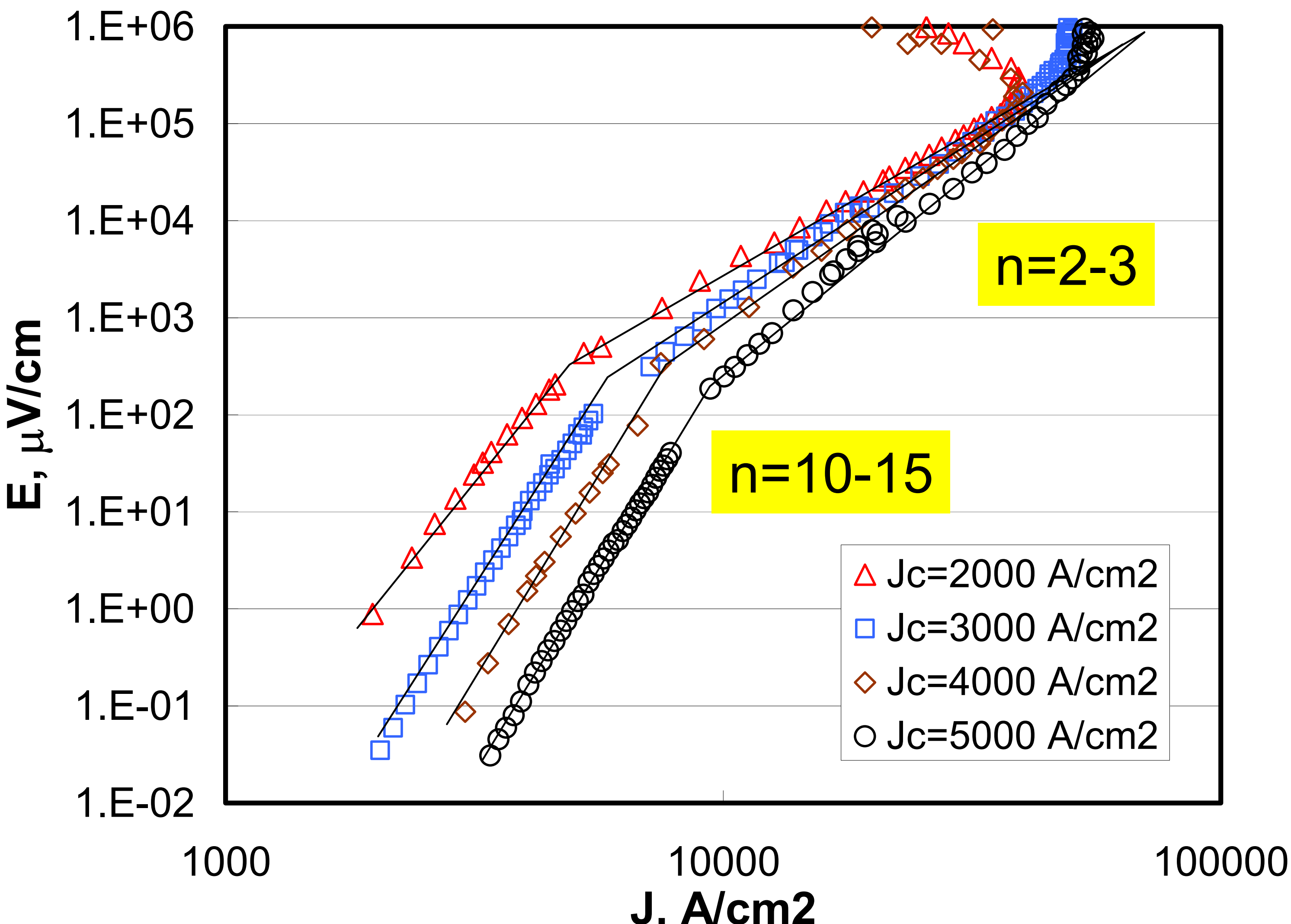
Bi-2212 bulk conductor

- 1.2 MVA "inductive" prototype: ✌👌👌
  tubes (ϕ = 40 cm)
  1 year operation in Swiss Hydropower Plant
- resistive/hybrid prototype: EA-tech. (& VA Tech)
  rods (0.25 x 2.5 x 25 cm^3)
- 6.4 MVA single phase "resistive" lab model: ✌👌👌
  plates (25 x 40 cm^2), steel bypass
- 10 MVA 3 phase resistive type: Nexans
  tube (ϕ 0.3 cm x 0.9 m), steel bypass

Nonlinear Characteristic of a Superconductor



E(j)-characteristic of Bi-2212 at 77 K



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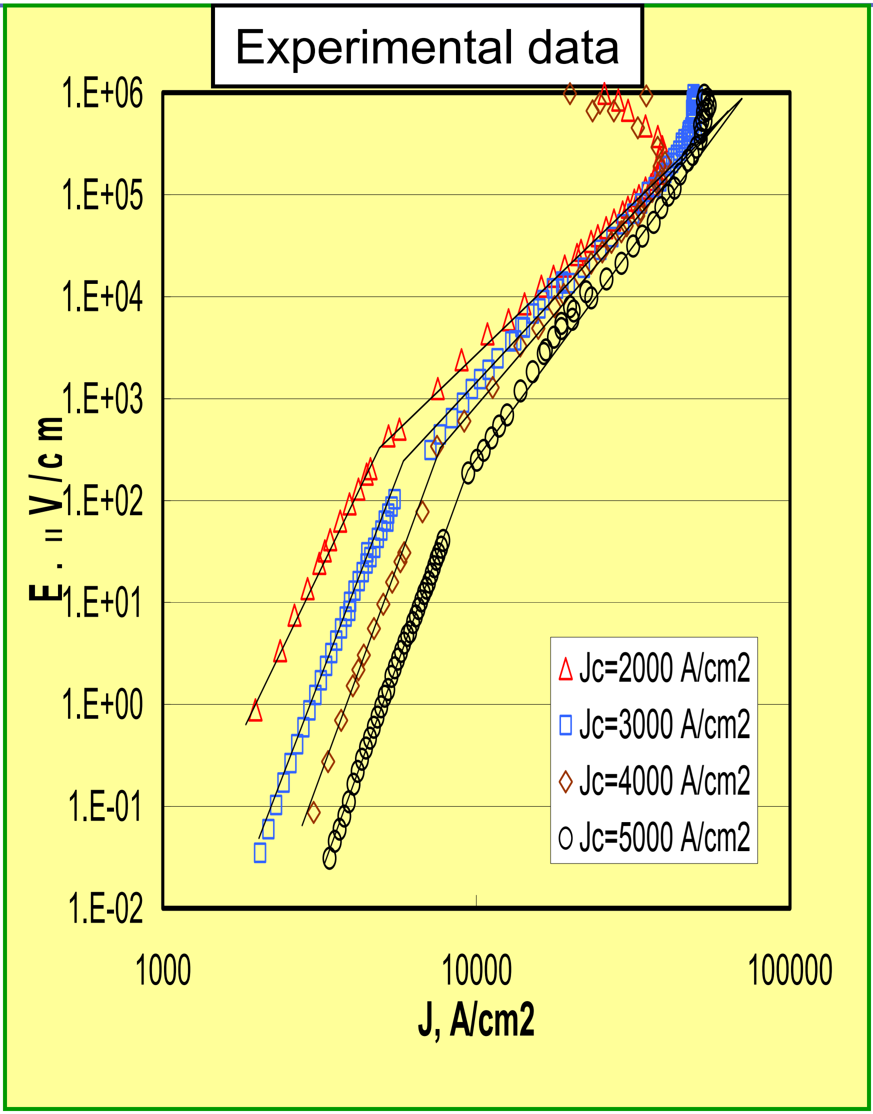

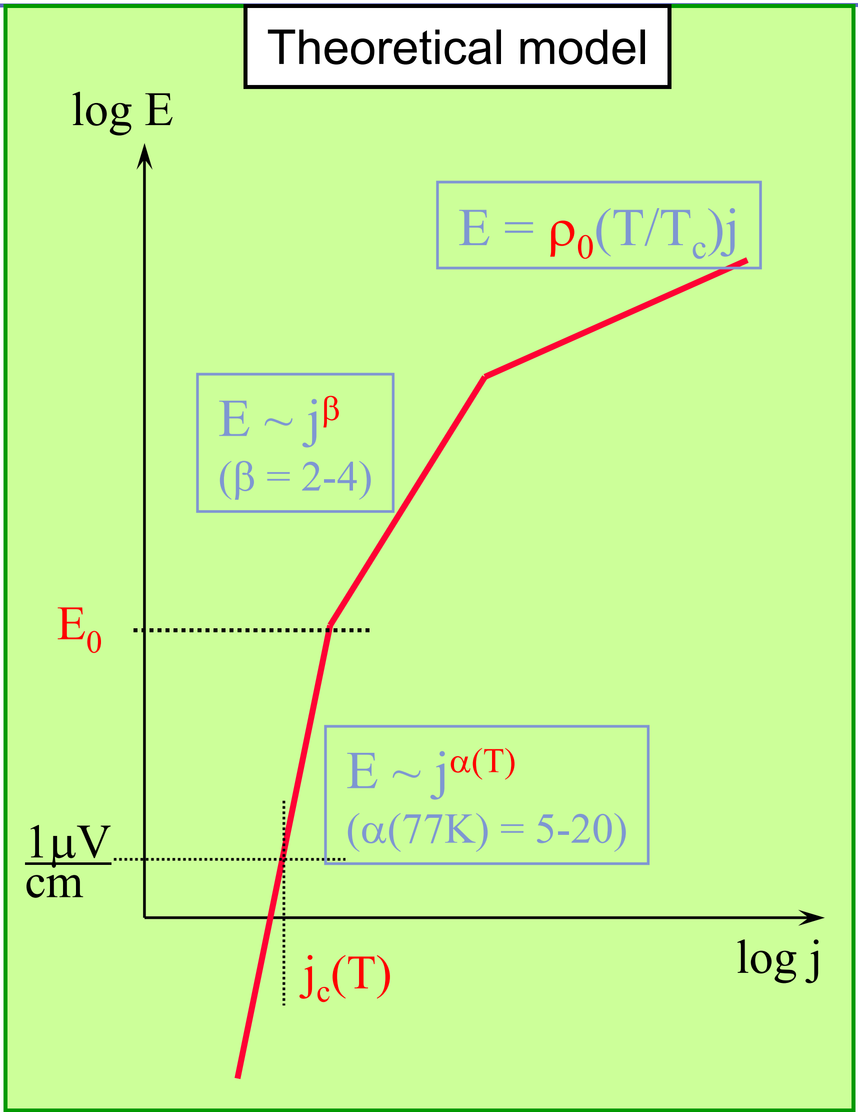

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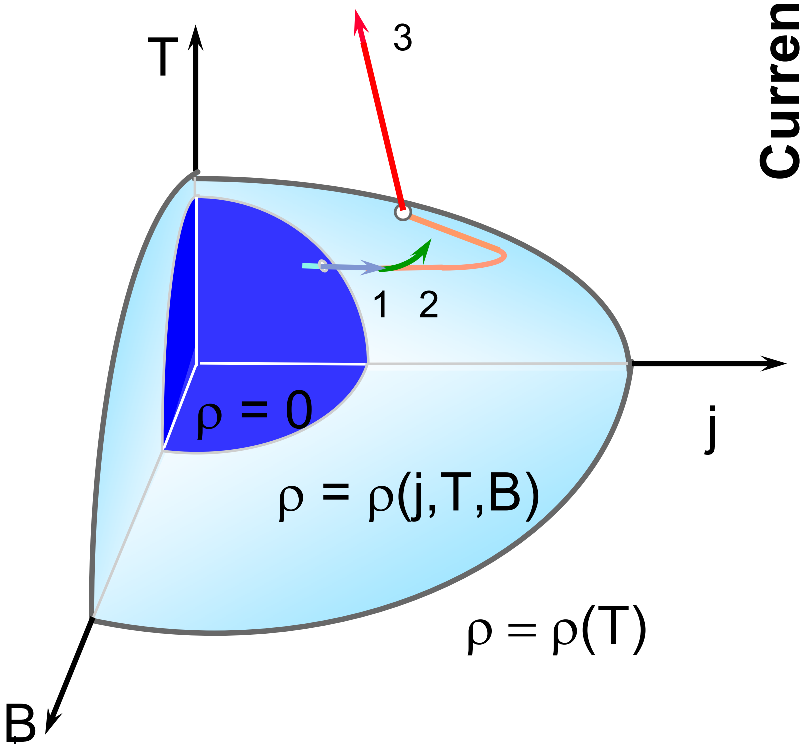
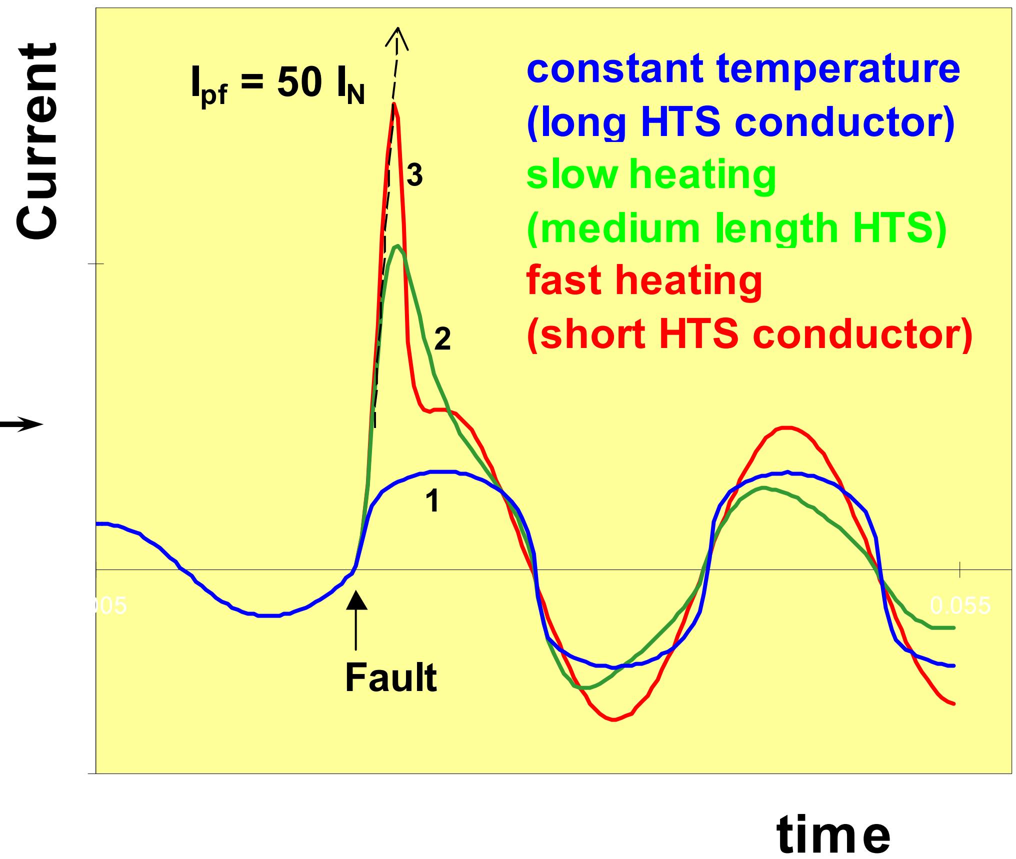
Basic principle of SCFCL





Test of 1.2 MVA SCFCL in Hydro power plant

The first HTS installation at utility site

KW Löntsch,Glarus, CH, 1996

- Instantaneous limitation
- no over-voltages
- recovery time: a few sec.
- no aging (within 1 year)
- open cooling system
  => high losses

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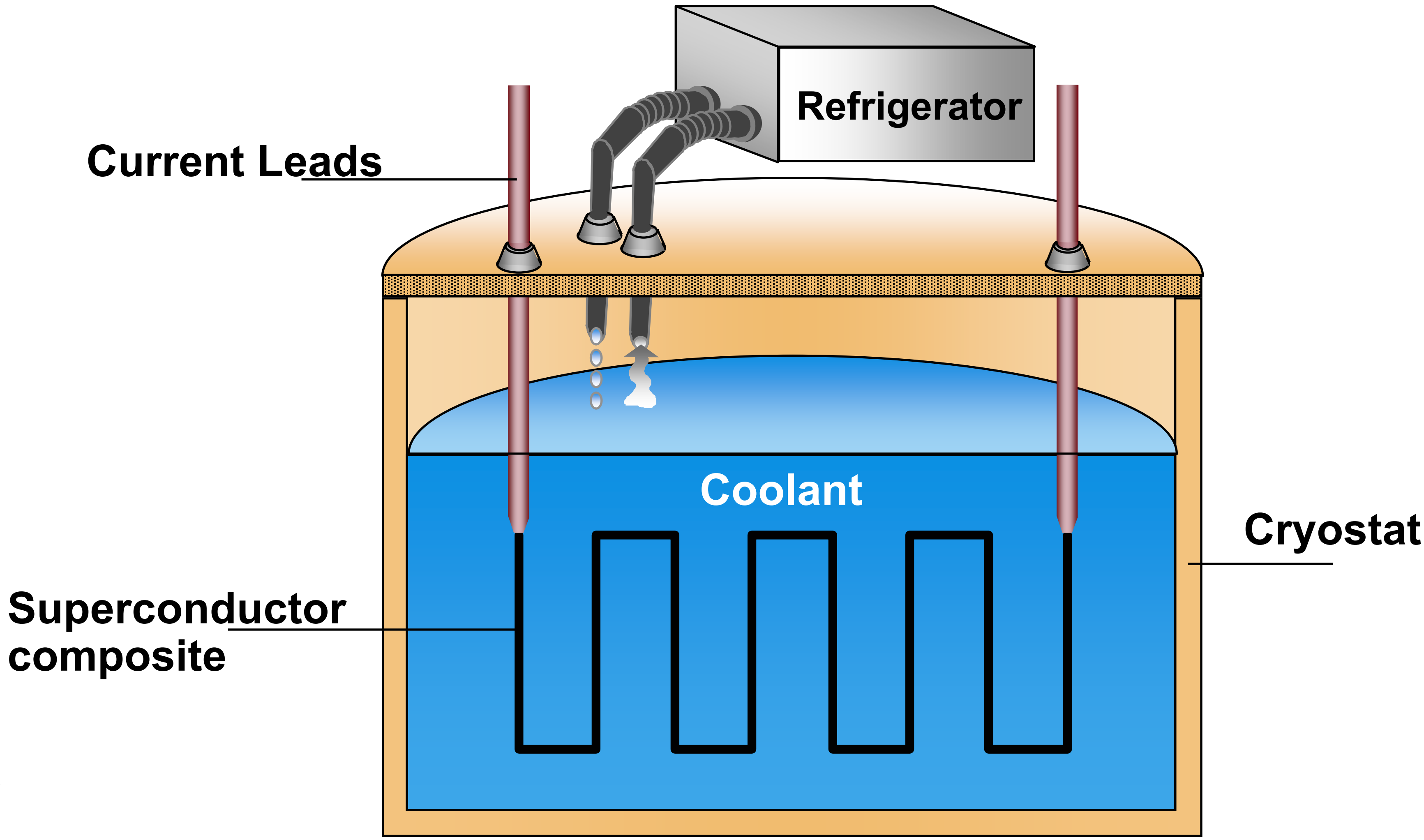
“resistive” SCFCL



Basic Design-Rules

Rated power: $P = I_N U_N$

Normal operation: $I_N = A j_c$

I_N = nominal current

j_c = critical current density, HTS

A = cross-section of HTS

Current Limitation: $U_N = L E_{max}$

U_N = nominal voltage

E_{max} = “max. electric field” of HTS

L = length of HTS

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Materials requirements

Normal operation:

=> reduce cooling cost

=> low ac-losses

=> small dimension ⊥ to B-field →thin conductor

=> field compensation →conductor design

Current limitation:

=> Non-uniform quench, i.e. hot-spots (voltage driven situation)

=> electrical and/or thermal stabilization

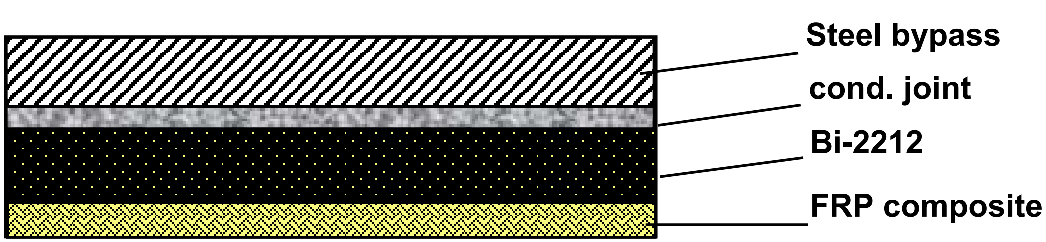
=> electrical bypass and/or heat sink

=> withstand high magnetic and thermo-mechanical stresses

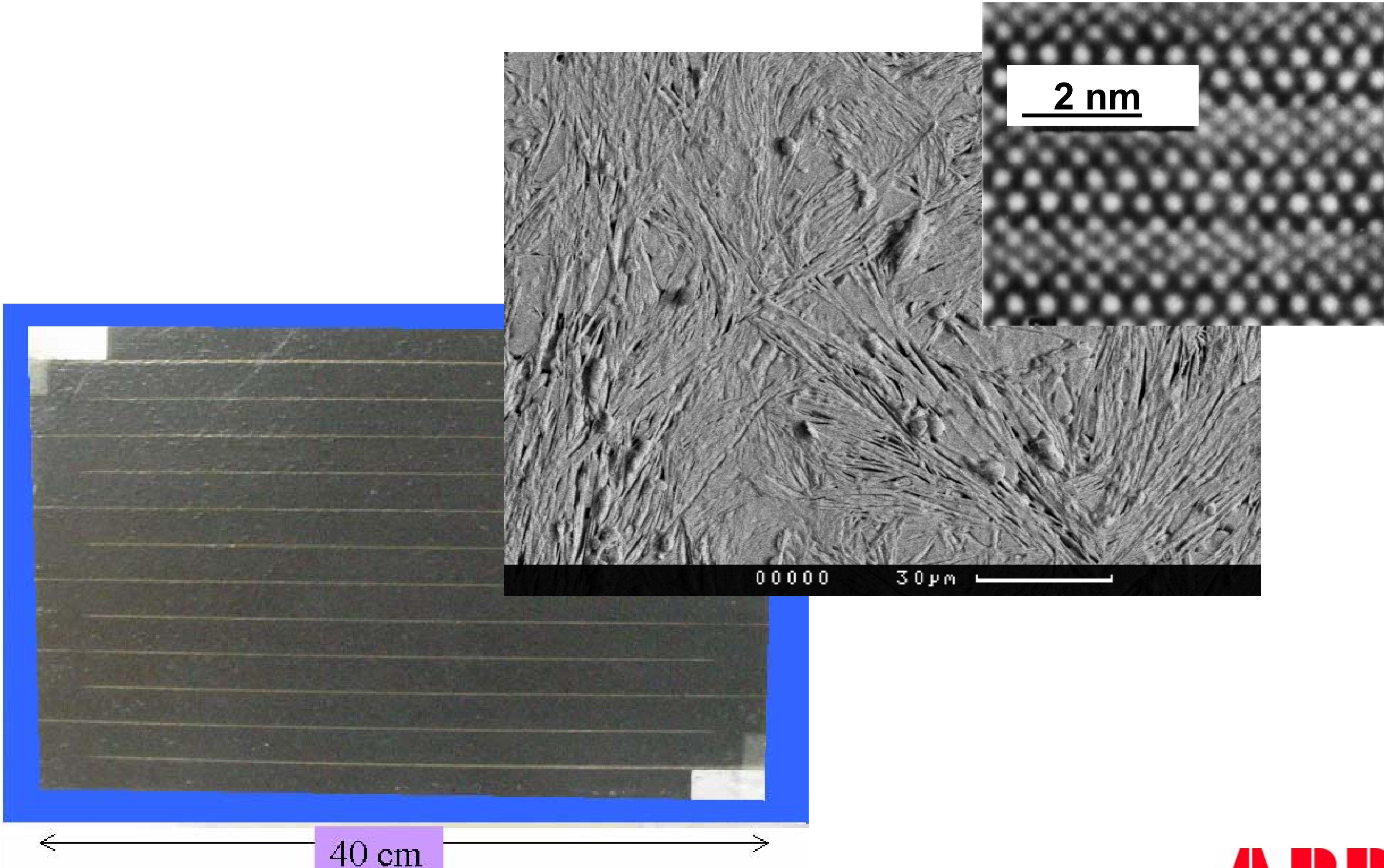
=> mechanical reinforcement (especially for brittle HTS-ceramic)

=> composites

⇨

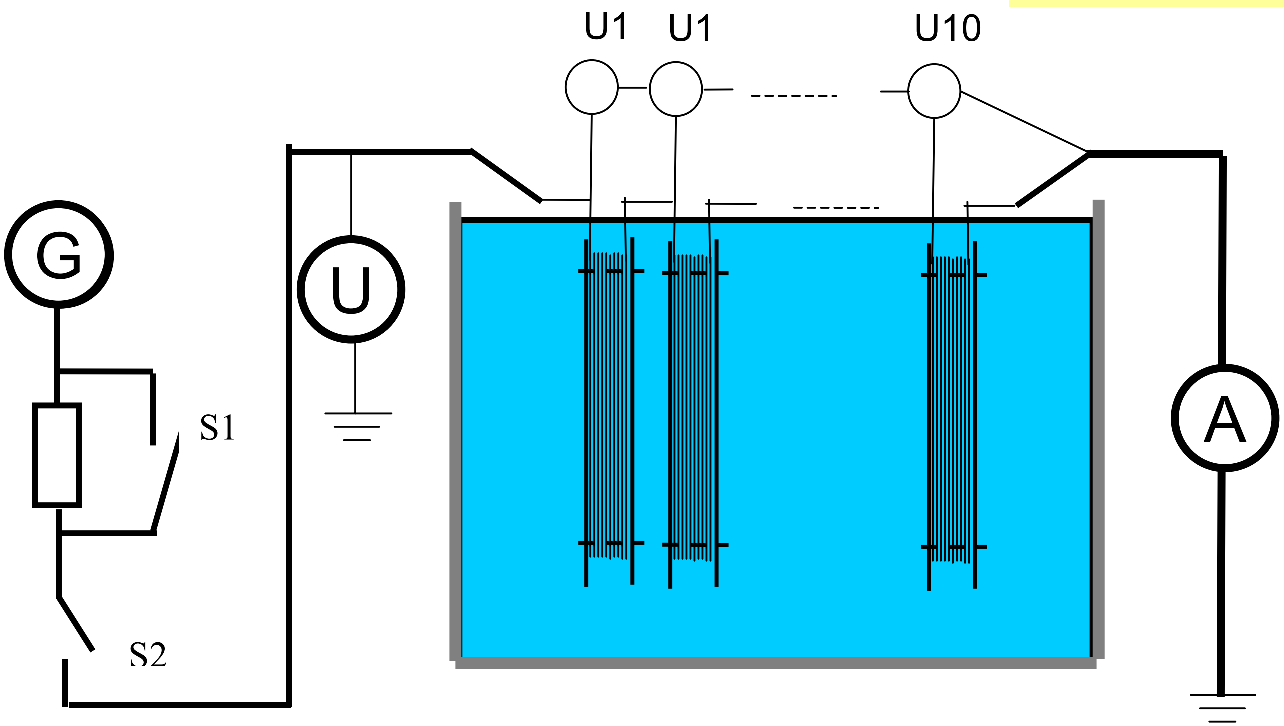


SCFCL component based on Bi-2212

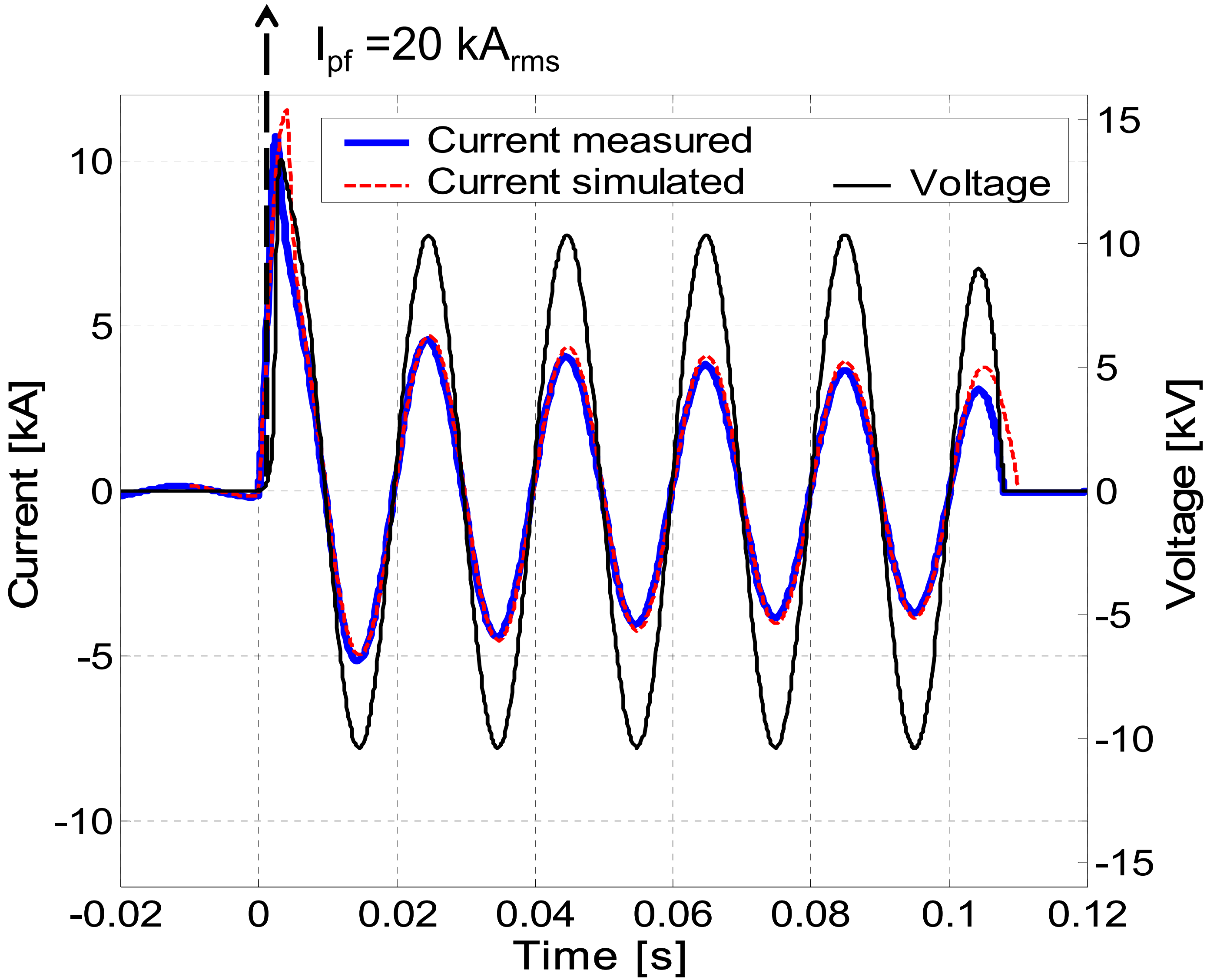


Test set-up of 6.4 MVA model

- U = 2.5 - 8 kVrms
- I_prosp = 17 – 20 kArms
- fault: symmetric & asymmetric
- Pulse: 100 ms



Test of 6.4 MVA laboratory model

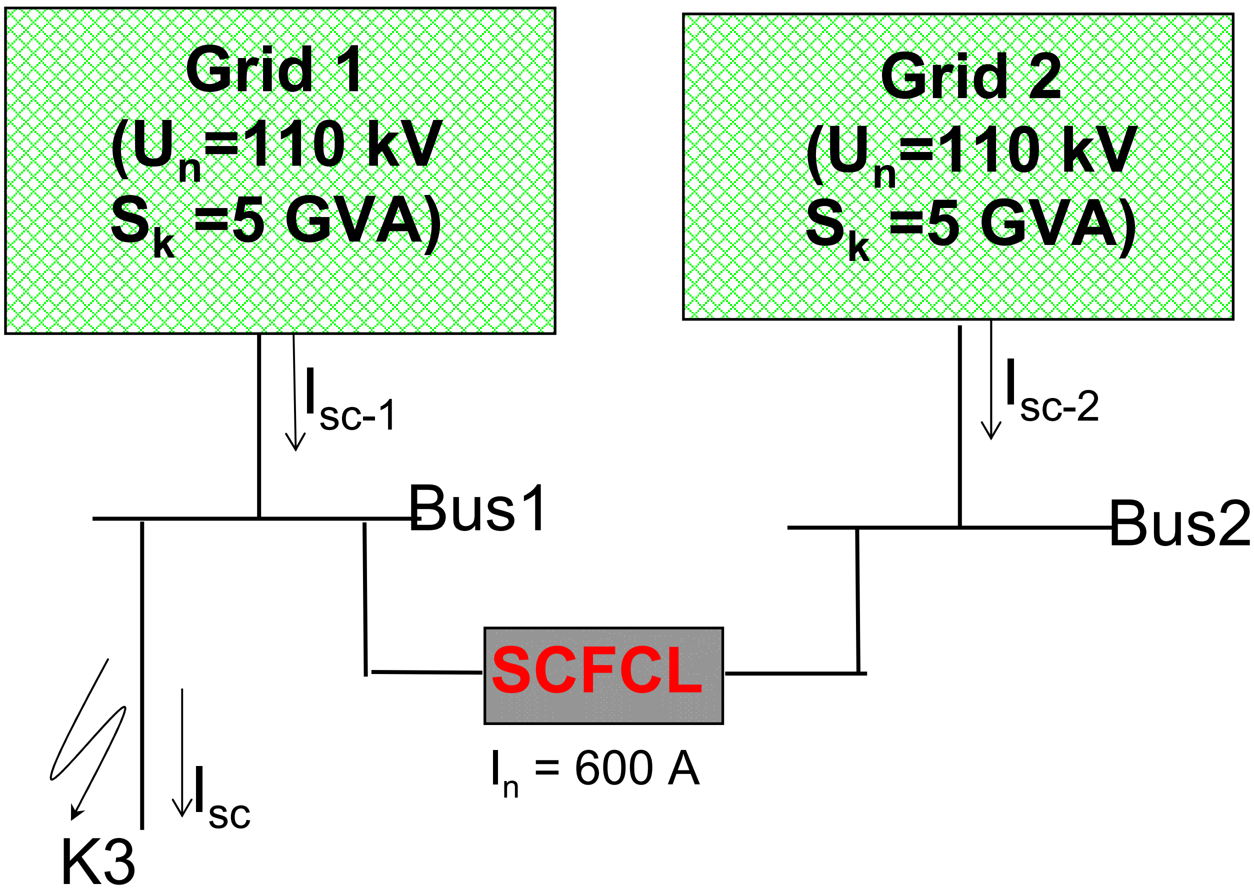


Applications for SCFCL

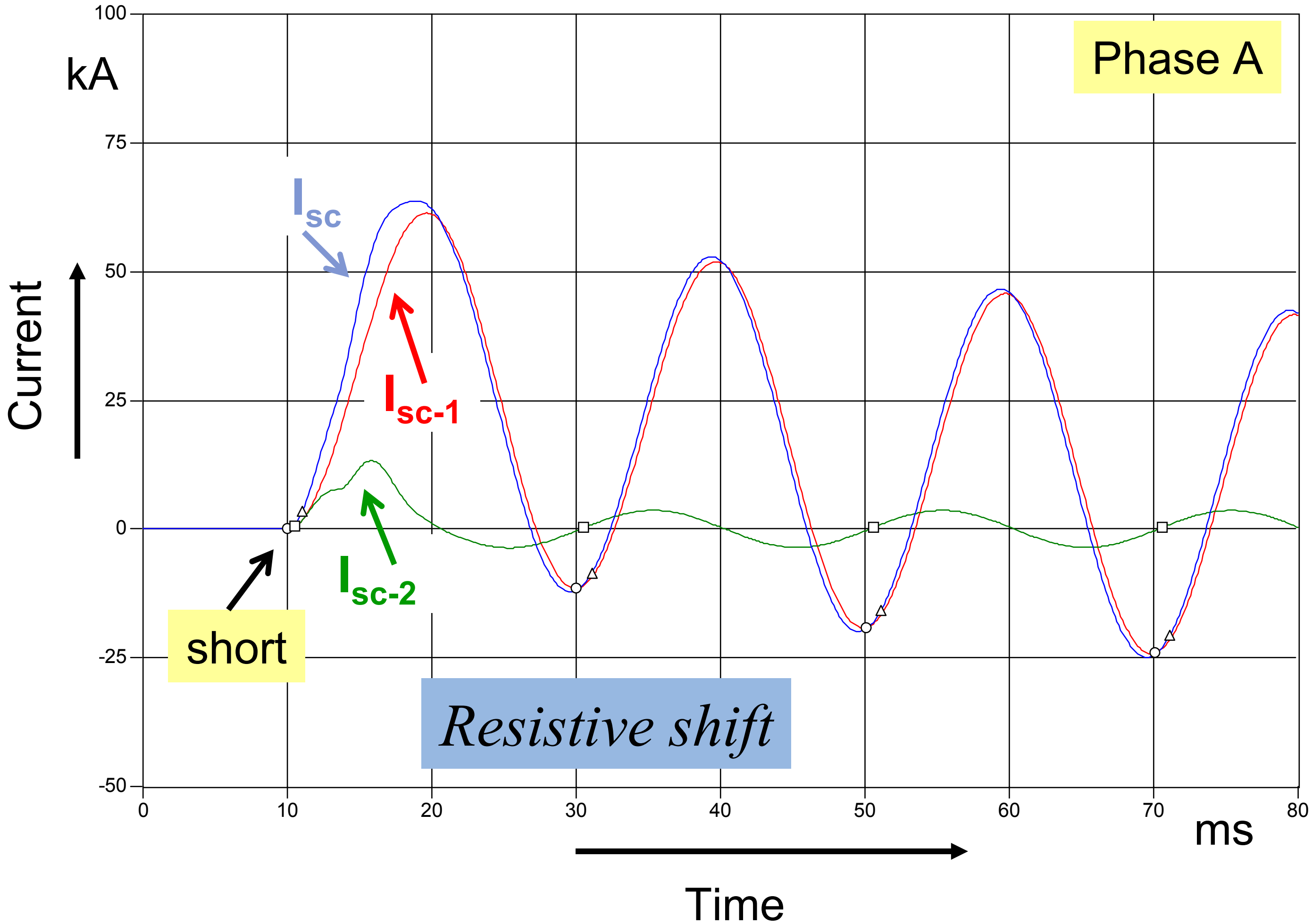
- ❐ Grids, where the I_{pf} has reached the design value of the breakers:
  - Grid-Coupling
  - Additional power source in existing grid (HV or MV)

- ❐ New installations where $I_{pf} / I_r >> 10$
  - Protection of Auxiliary Line
  - Supply of local industry on MV-level
  - Several generators connected to one busbar
  - Transformer with reduced impedance
  - New grids (industrial, distribution, transmission)

Grid Coupling –RWE case



Simulation of short circuit in coupled grid



Application Challenges

- **Conductors**
  - Reliability: repetitive operations
  - Cost: reduce high price / performance (=transformer)
  - Technical spec: **oco** immediate reclosure may be required
  - Limitation factor: high jc needed for better limitation
- **Cooling system**
  - First investment: price has to come down
  - Maintenance: minimum maintenance
  - Refill system: possible in a group
- **Customer acceptance**
  - Conservative approach: LN2
  - Reliability, availability
  - Back up solution: needed initially

Way forward

- **Technology maturity**
  - demonstrator demonstrated, meeting some commercial applications
  - Ready for functional prototype
- **Pre-commercilisation**
  - More detailed evaluation needed (technical spec vs future grid)
  - Full scale functional prototype needed to demonstrate for application
- **Commercialisation**
  - Niche application, e.g. grid coupling
  - Full application depends on low cost conductor and much reduced cooling
  - Full commercial potential depends on up-scaled prototype, better conductor

- Functional prototype needed
- Limited application in niche areas possible
- Large scale application ←low cost conductor & low cost reliable cryogenic

Conclusions

- SCFCL composite component based on Bi-2212 developed
- 6.4 MVA single phase SCFCL developed
- SCFCL technology (Bi-2212) justify functional prototype
- Potential first application evaluated
  - particularly suited for high prospective fault current
  - ideal performance for grid coupling
- Functional prototype needed for
  - customer acceptance and field experience
  - confirmation of market
- Limited application in niche areas possible
- Large scale application critically depends
  - low cost conductor
  - low cost reliable cryogenic
  - improved materials performance

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