Characterizing the Performance of Nb_3Sn Accelerator Magnets with Advanced V-I Measurements

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*A **spot-like, local inhomogeneous, degradation** in a Rutherford cable causes **current redistribution**, which leads to **decaying voltages** on the current plateaus of **V-I measurements.***

Advanced V-I measurements

- High resolution V-I measurements are used to determine conductor degradation.
- Voltages over coil cable segments measured on plateaus of a staircase-type current ramp.

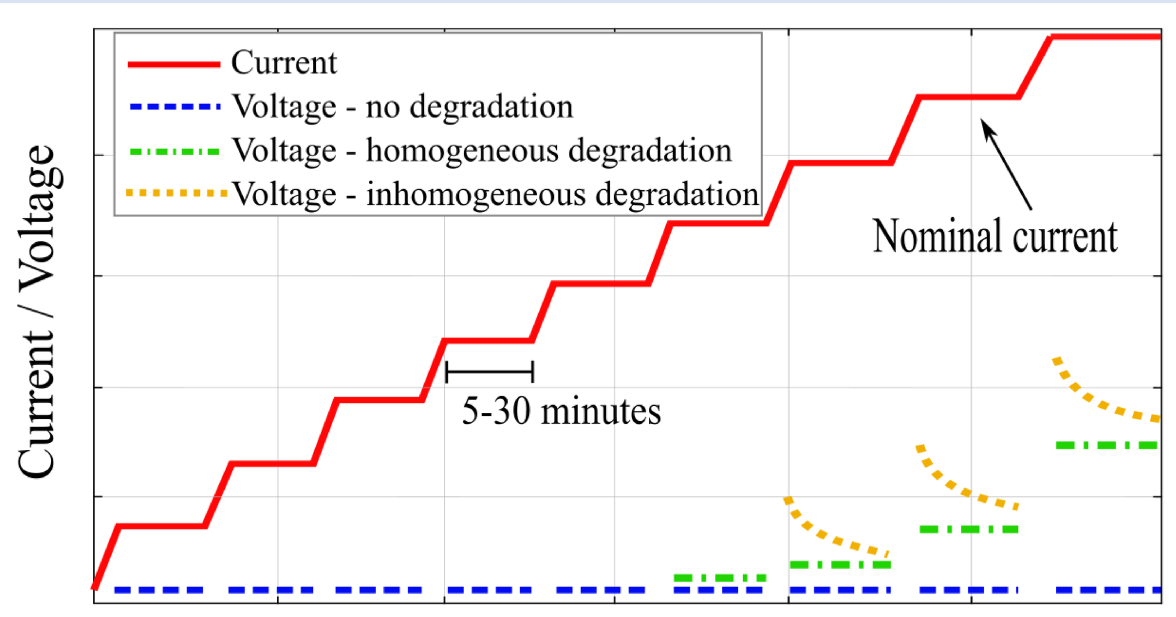

Figure 1

- Voltage build-up on successive plateaus indicates conductor degradation.
- **Constant voltage → homogeneous degradation.**
- **Decaying voltage → local degradation.**

Decaying voltage

Certain HL-LHC type of magnets show decaying voltages [1]:

- Time constant of the order of 100 to 1000 s,
- Range from of 0 to 20 μV,
- Can be simulated with a continuum model.

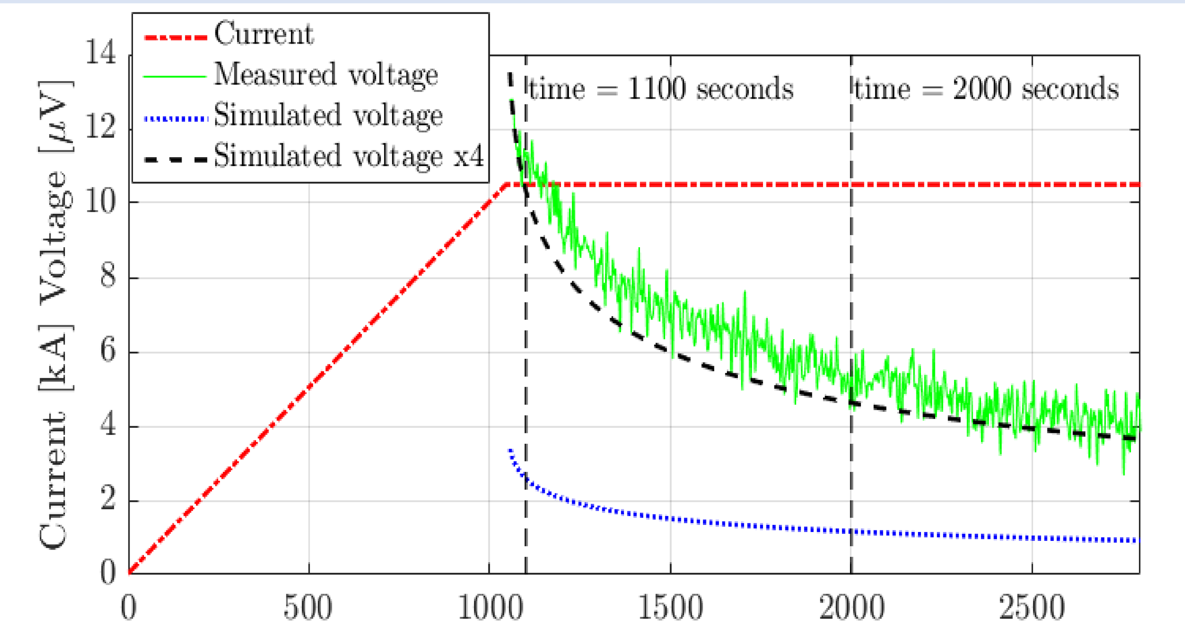

Figure 2

Hypothesis and Model

- Decaying voltages caused by a spot-like degradation in the Rutherford cable.
- Current then redistributes around the degraded spot through a current diffusion process.

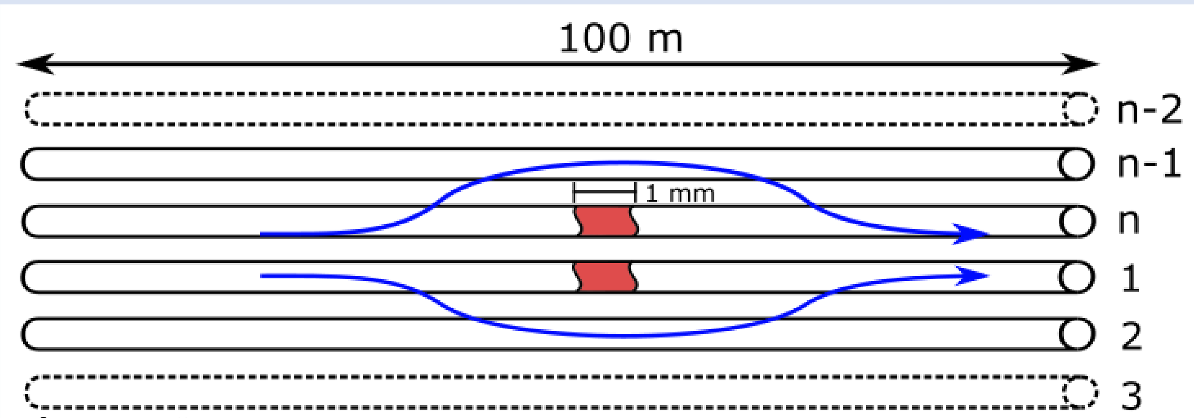

Figure 3

- A disitributed parameters model is used: a subset of strands have a local, full or partial degradation, to study the general behaviour of the current redistribution process [2], [3].

Results

Simulation of 16 strand cable & 6 degraded strands:

- Figure 4 shows time evolution of current at position of degradation.
- 8 strands are shown, since model is symmetric.
- Strands 1 to 3 carry no current.
- **Adjacent strand 4 initially carries all excess current.**
- When strand 4 reaches critical current → current cascades to neighboring strand 5.

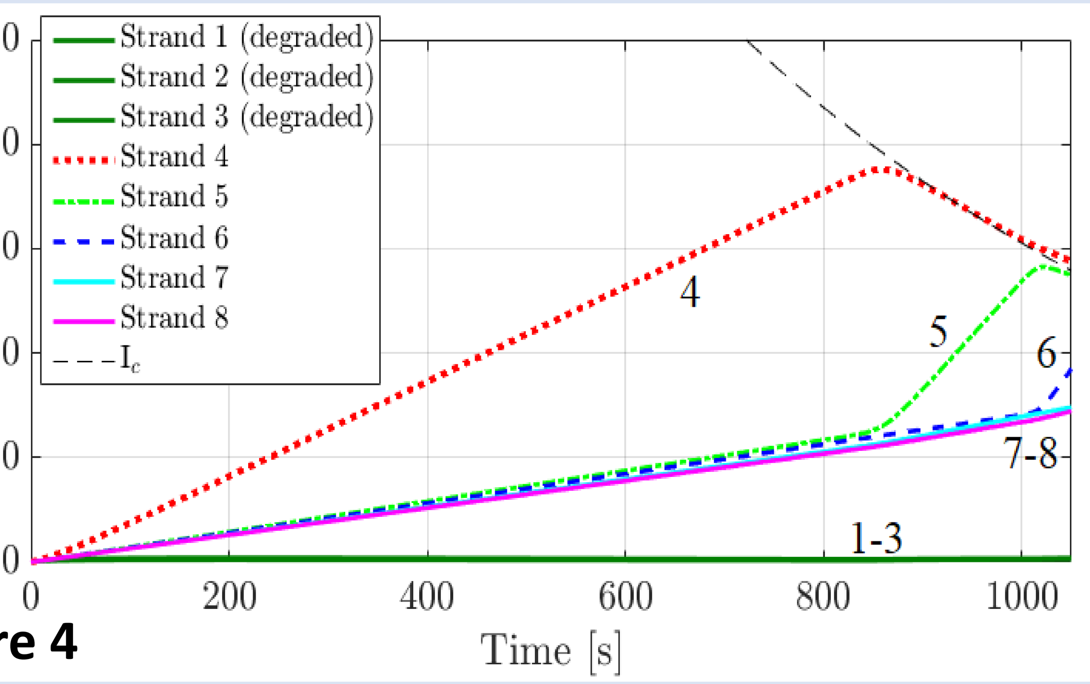

Figure 4

Current profile in strands around a bad spot

- Current imbalance **extends over more than 10 meter** away from the degraded region.
- Profile widens with time → voltages decrease.

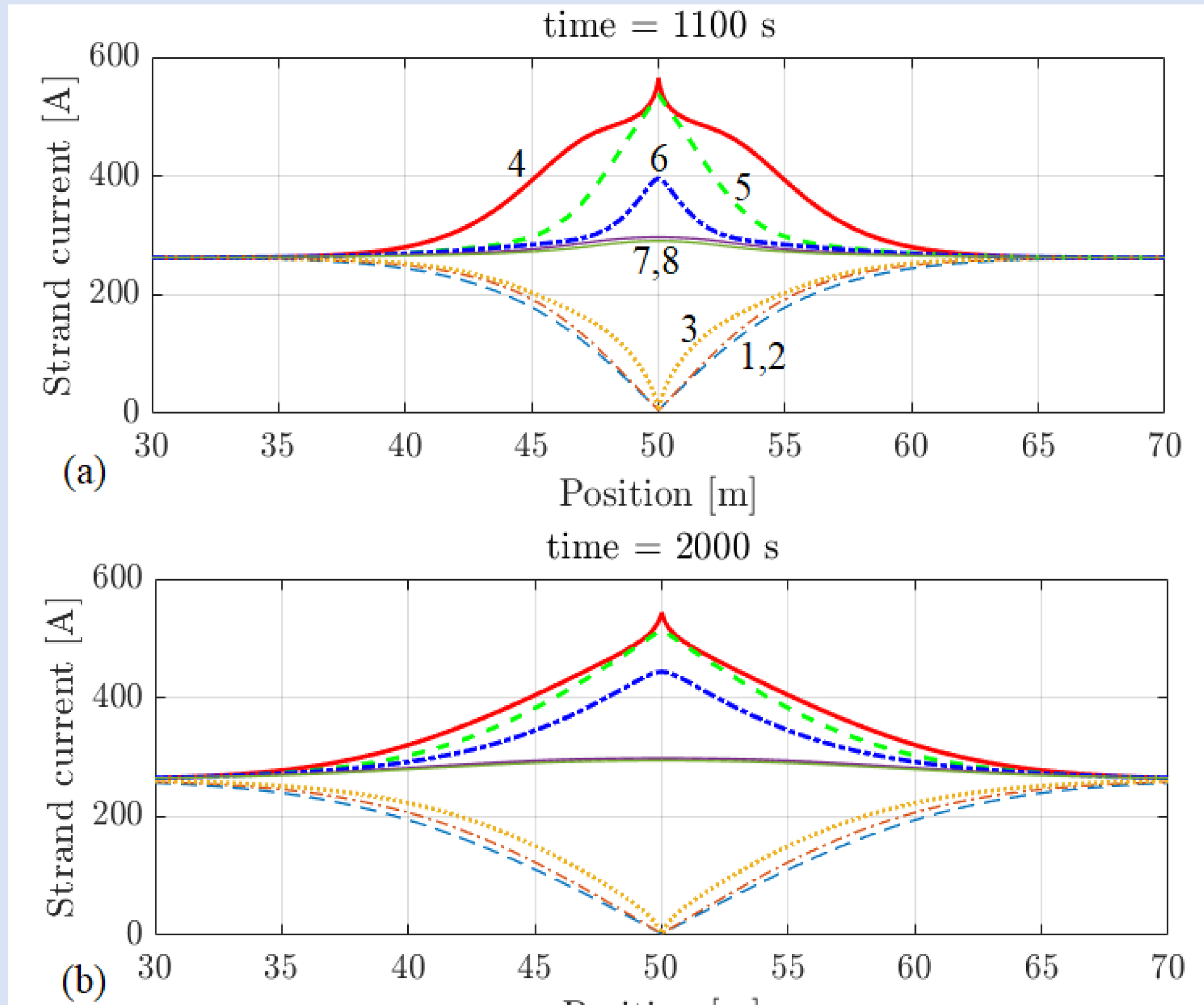

Figure 5

Voltage profiles

- Voltage rise in degraded strands close to defect.
- Degraded strand → sharp voltage drop.
- Intact strand → gradual voltage drop.
- **Measuring in front or after the degraded region, (V_1-V_2) can yield a negative voltage.**
- Measuring over the degraded region (V_2-V_3) always yields a positive voltage.

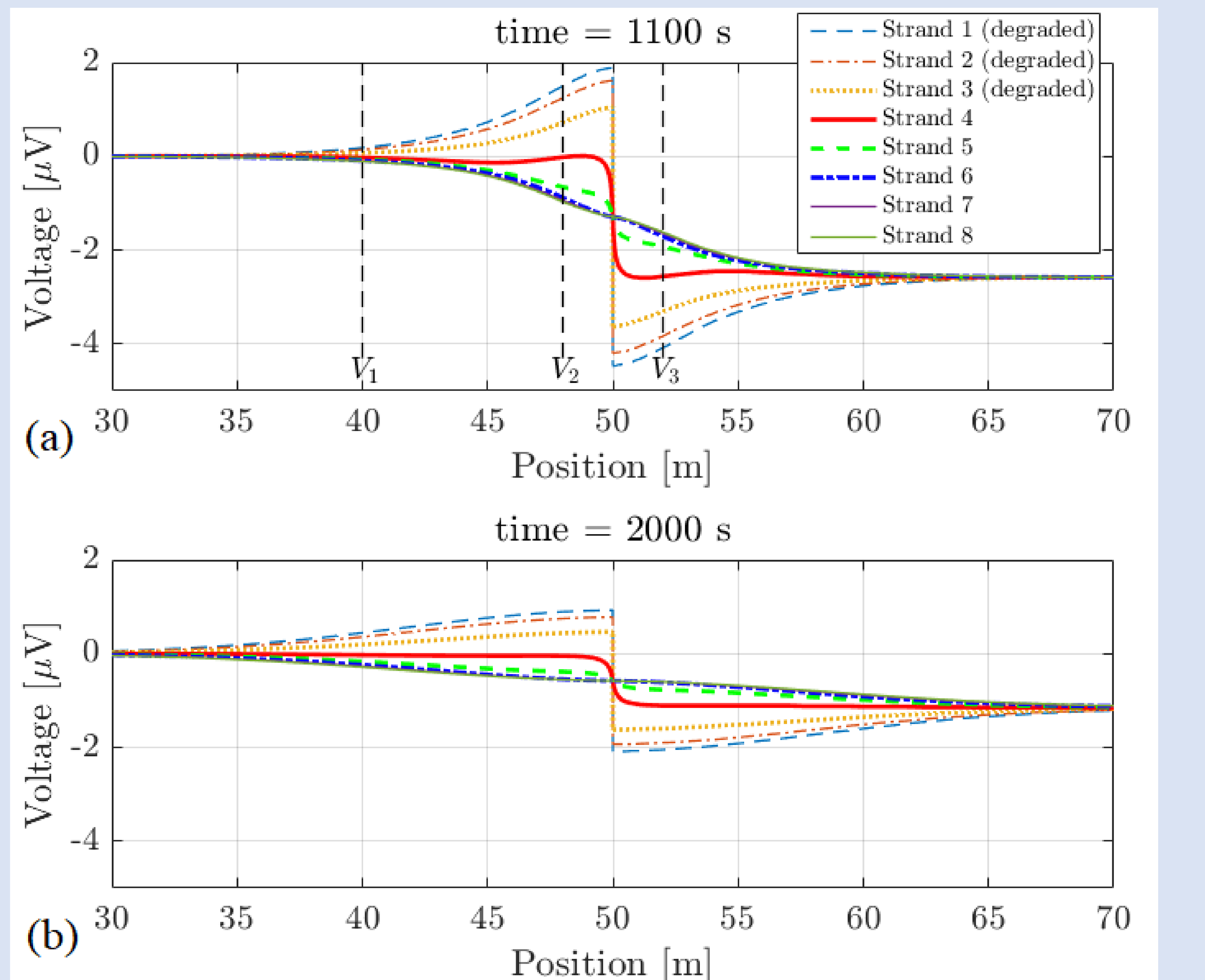

Figure 6

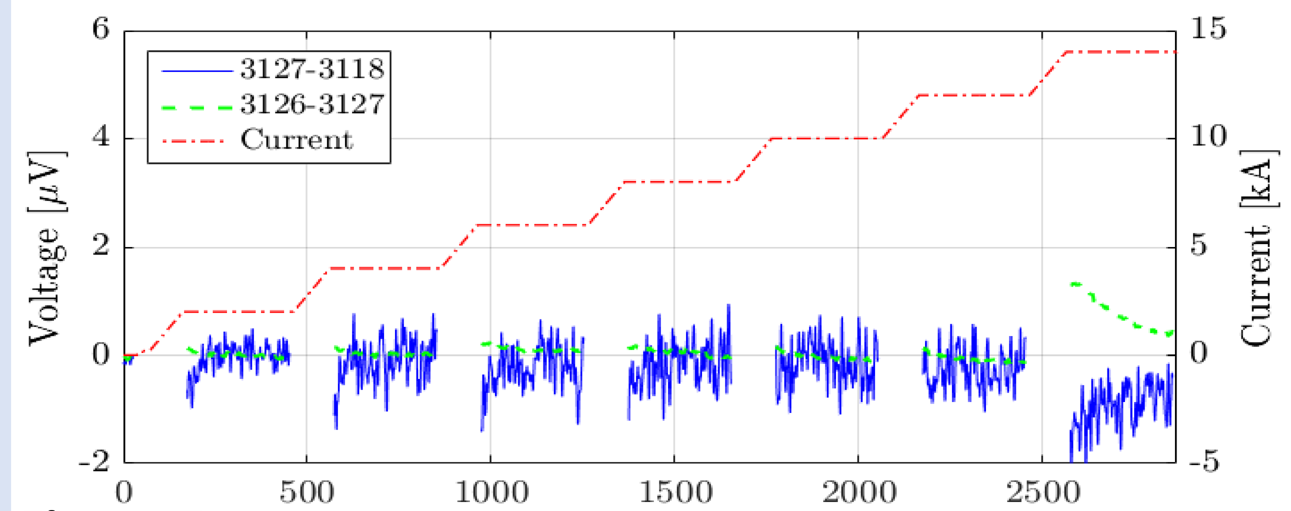

Figure 7

Fig. 7 shows a measured example of positive and negative decaying voltages over conductor sections [4]

Ramp sequences

- More complex ramp sequences can also be matched.
- Time constants during start of last 3 current plateaus are smaller in the simulated voltage.

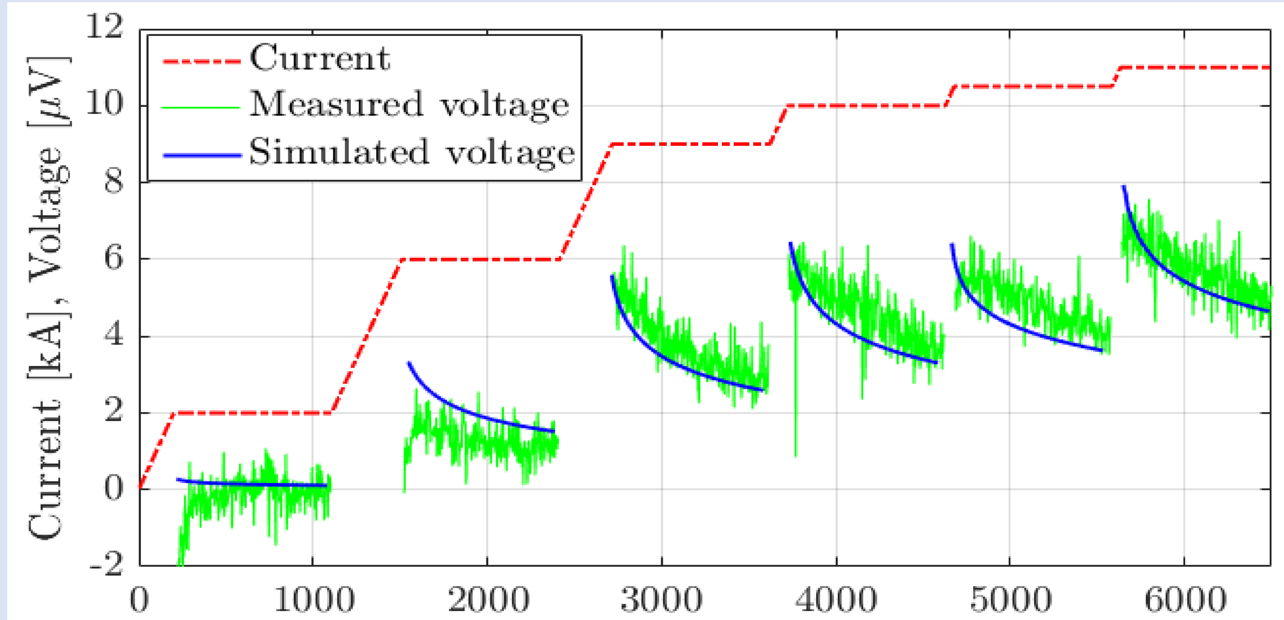

Figure 8

Key issues and Next steps

- What is the impact of the current imbalance on:
  - Stability,
  - Early quench development,
  - Quench propagation velocity.

References

[1] G. Willering "MBHA002 final test report", https://edms.cern.ch/document/2611118/1

[2] L. Bottura, C. Rosso, M. Breschi "A general model model for Thermal, Electric and Hydraulic Analysis of superconducting cables" Cryogenics 40 (2000) 617-626.

[3] A. Akhmetov, L. Bottura, M. Breschi, P. L. Ribani, "A theoretical investigation in flat two-layer superconducting cables" Cryogenics 40 (2000) 627-635.

[4] F. J. Mangiarotti et al., "Power Test of the First Two MQXFB Quadrupole Magnets Built at CERN for the HL-LHC Low-Beta In-sertion" IEEE Trans. Appl. Supercond. *Not yet published.*

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