Ice on the overhead contact wire (OHL) for AC electrified railways

Status report from the OHL Ice Working Group

Lars Buhrkall, Sviegade 3, DK - 6760 Ribe. Tel. +45 74846011, Email lars@buhrkall.dk, www.buhrkall.dk

Reported problems

- Exceedance of the interference limits of DC track circuits (Sweden, Denmark, Luxembourg, UK), and of 100 Hz track circuits (Switzerland)
- Incompatibility with protection systems, causing train stops (Sweden, Denmark, UK)

Working Group

- Initiated at the first ESC UserGroup workshop last February
- Representatives from Banverket, SBB, Uni Luleå, Bombardier, Siemens, DSB
- Meetings on an irregular basis

Activities

- Understand the meteorological conditions that lead to ice accretion
- Understand the theory of arcing and the mechanism of DC generation
- Lab measurements with a test rig
- Analysis of readily available field data
- Field measurements
- Simulation models including transformer saturation

Lars Buhrkall, Sviegade 3, DK - 6760 Ribe. Tel. +45 74846011, Email lars@buhrkall.dk, www.buhrkall.dk

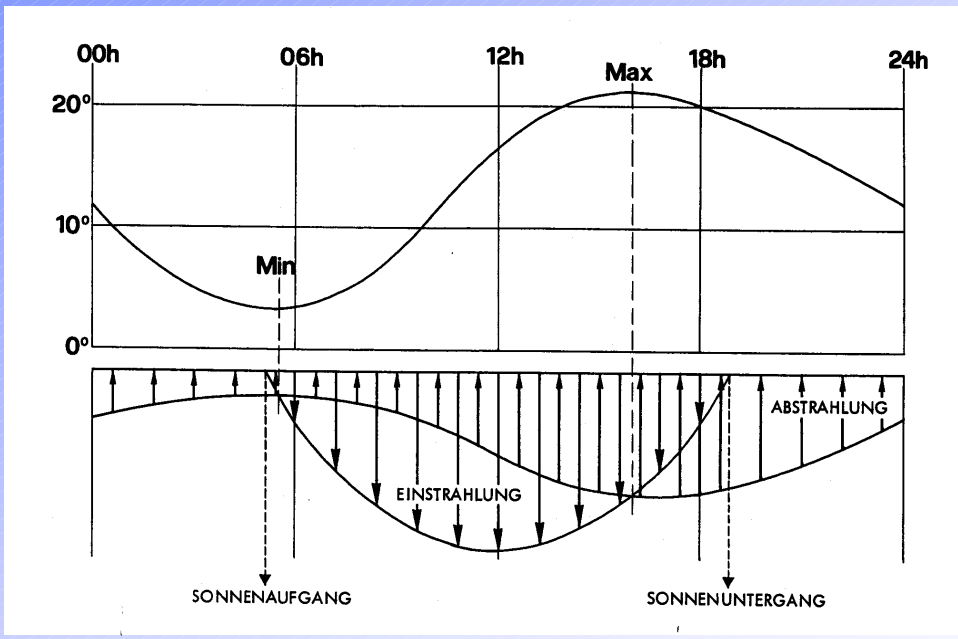
Ice accretion – 3 mechanisms

Ice type	**Mechanism**
Hoarfrost	Air humidity freeze on surfaces directly from the vapour phase
Rime	Air humidity condensate on surfaces ($T < T_{DEW}$) and freezes ($T < 0°C$)
Glaze	Water droplets (e. g., supercooled rain) hits a cold surface and freezes

Lars Buhrkall, Sviegade 3, DK - 6760 Ribe. Tel. +45 74846011, Email lars@buhrkall.dk, www.buhrkall.dk

Meteorological Conditions: Radiation

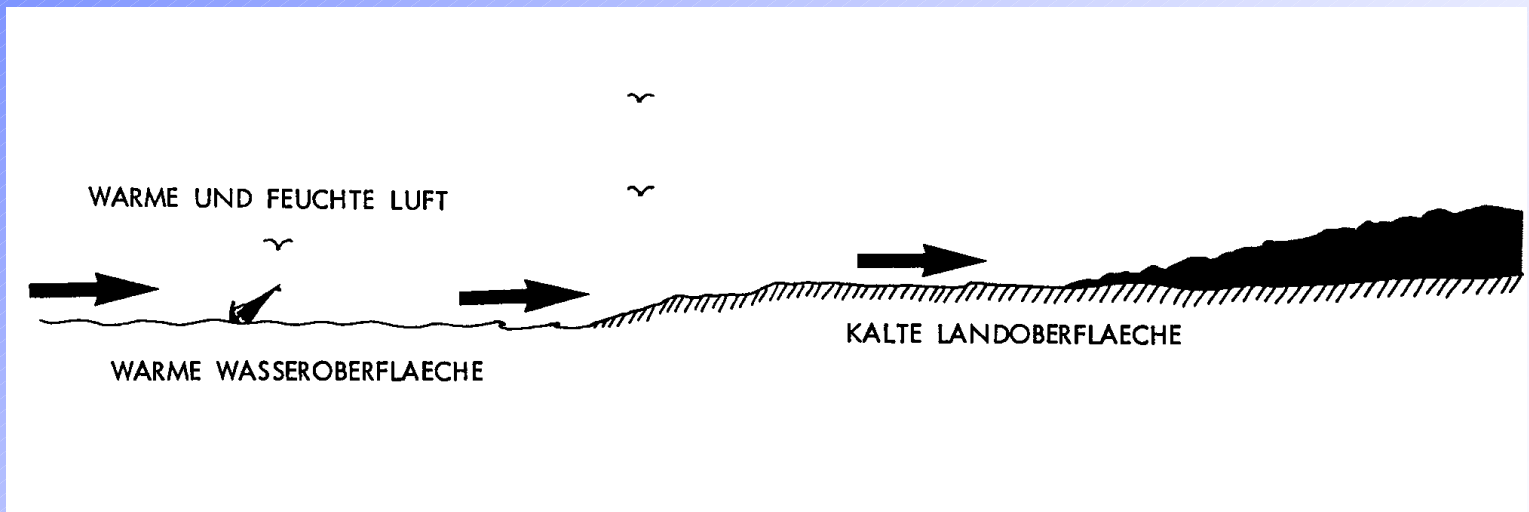
- High air humidity in the evening
- Clouds disappearing during the night
- Cooling down due to radiation to space



Lars Buhrkall, Sviegade 3, DK - 6760 Ribe. Tel. +45 74846011, Email lars@buhrkall.dk, www.buhrkall.dk

Meteorological Conditions: Advection

- The temperature is below 0°C
- A quiet wind brings in warmer air with a high humidity



Lars Buhrkall, Sviegade 3, DK - 6760 Ribe. Tel. +45 74846011, Email lars@buhrkall.dk, www.buhrkall.dk

Initial observations and experiences

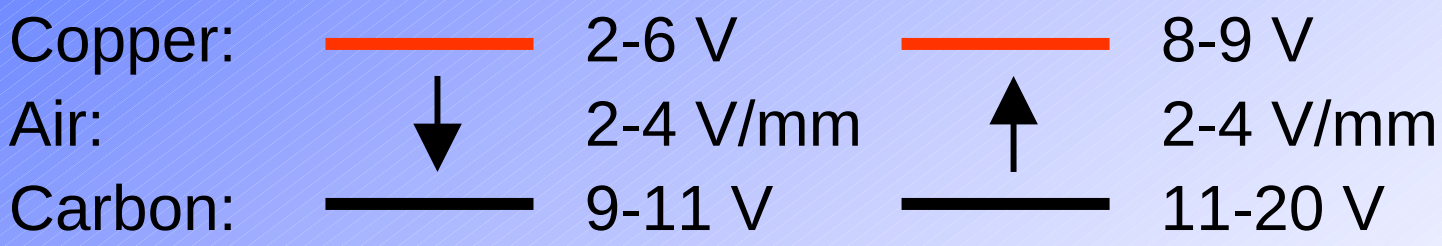
- The OHL ice produces a clearly visible arc
- DC components and even harmonics are measured in the line current
- The DC seems to be unidirectional
- Copper and carbon have different electrochemical properties

Lars Buhrkall, Sviegade 3, DK - 6760 Ribe. Tel. +45 74846011, Email lars@buhrkall.dk, www.buhrkall.dk

Fundamental arc physics

3 zones: The two electrodes 0.01-0.1 mm thick, and conducting plasma in between

Cathode and anode voltage drops:



The cathode spot:

- The electrons are emitted from the cathode spot
- The voltage required to ignite an arc depends on material, temperature, ionization, shape, etc.

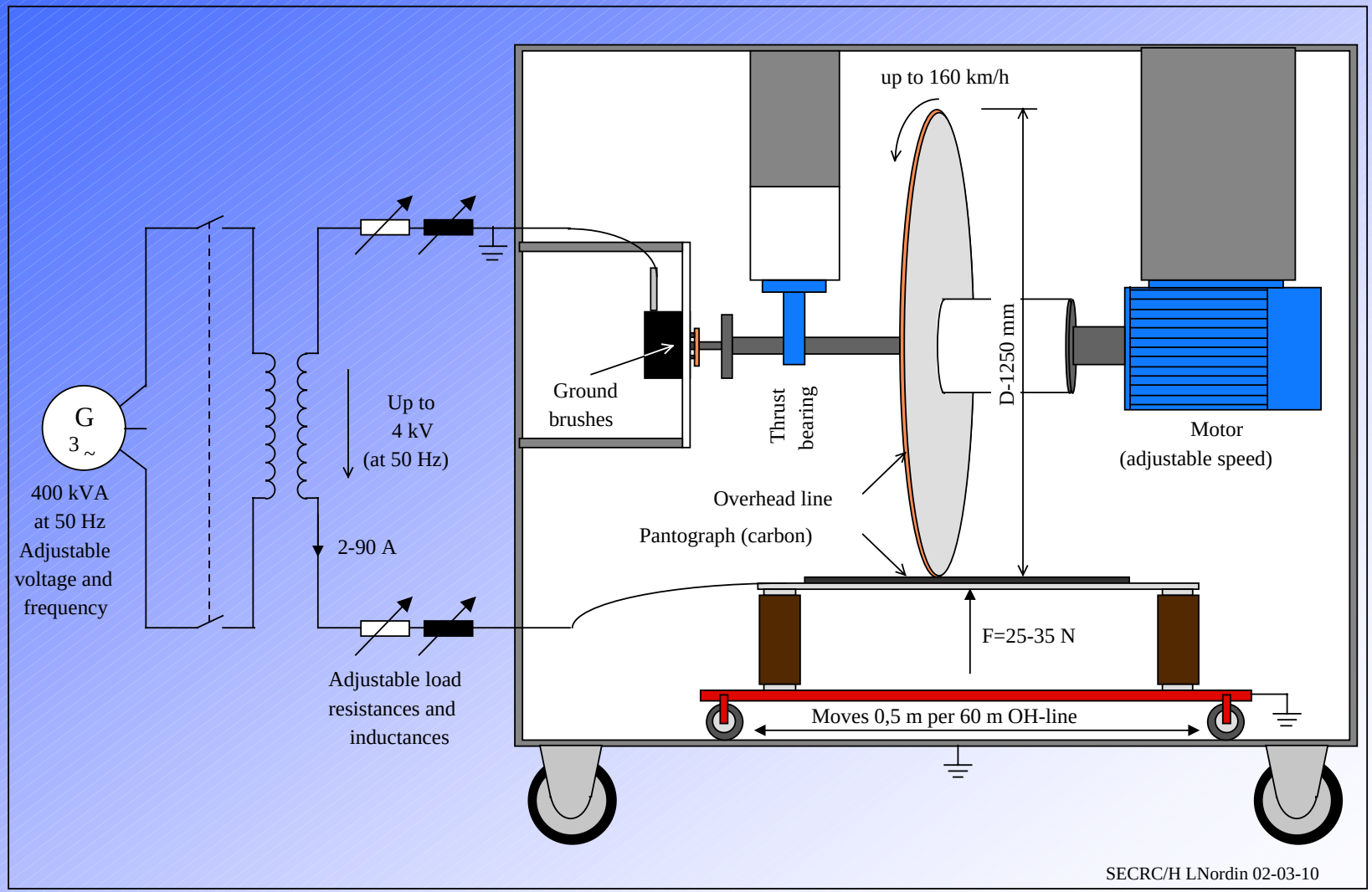
Lars Buhrkall, Sviegade 3, DK - 6760 Ribe. Tel. +45 74846011, Email lars@buhrkall.dk, www.buhrkall.dk

3 DC generation mechanisms

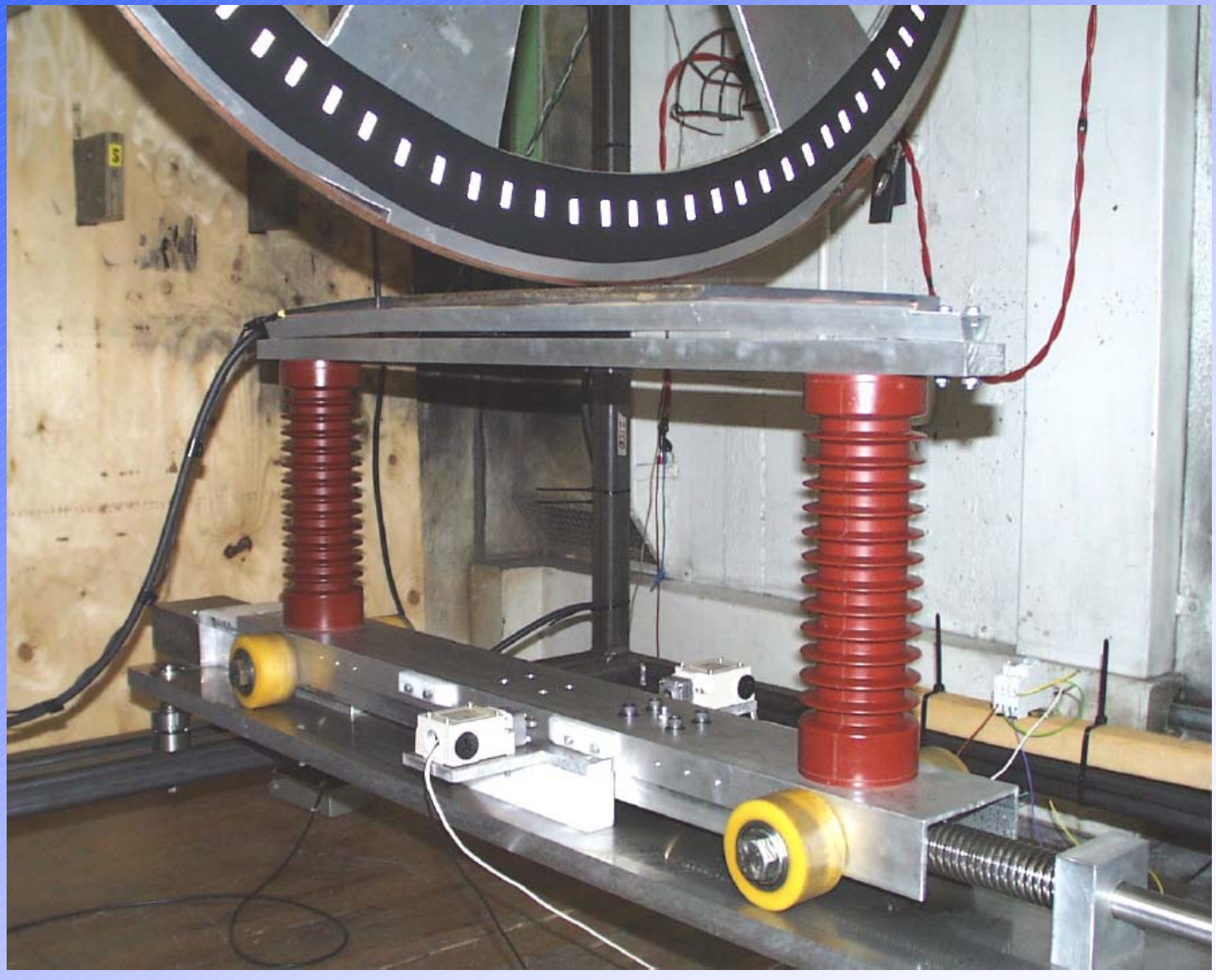
Continuous arc	• The arc voltage drop depends on the direction of the current • Net EMF of 5-18 V DC (”+” on the carbon)
”Jumping” arc	• The arc ignition voltage is polarity dependent, and higher than the voltage drop across the arc itself • The arc ”jumps” along the OHL • Higher net EMF, up to 100 V DC
Discontinuous arc	• The arc is extinguised at the zero-crossings of the current • The ignition voltage is polarity dependent

Lars Buhrkall, Sviegade 3, DK - 6760 Ribe. Tel. +45 74846011, Email lars@buhrkall.dk, www.buhrkall.dk

Lab test set-up

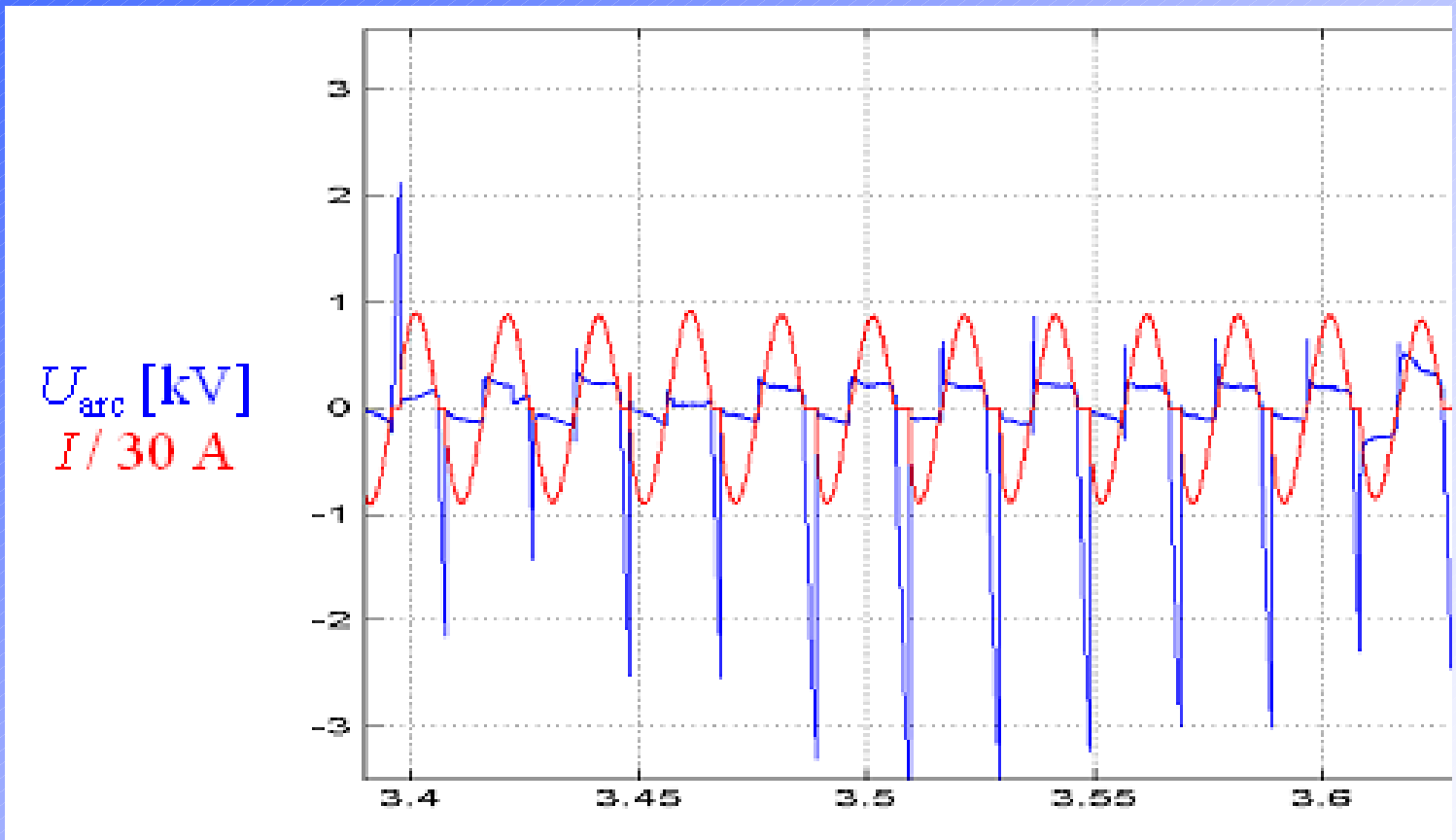


Lars Buhrkall, Sviegade 3, DK - 6760 Ribe. Tel. +45 74846011, Email lars@buhrkall.dk, www.buhrkall.dk



Lars Buhrkall, Sviegade 3, DK - 6760 Ribe. Tel. +45 74846011, Email lars@buhrkall.dk, www.buhrkall.dk

Lab test results



Discontinuous arcing, mechanism 3 (zero-crossings!)

The net EMF is approximately 106 V in this example

Lars Buhrkall, Sviegade 3, DK - 6760 Ribe. Tel. +45 74846011, Email lars@buhrkall.dk, www.buhrkall.dk

Lab test conclusions

- The arc ends jump along both electrodes, mechanism 2 is also valid
- The DC EMF decreases with increasing arc AC voltage and increasing current
- The DC EMF increases with with increasing electrode distance and increasing speed
- The dependency on cos(ø) is unclear

Lars Buhrkall, Sviegade 3, DK - 6760 Ribe. Tel. +45 74846011, Email lars@buhrkall.dk, www.buhrkall.dk

Field tests

1 and 2 BR185 locomotives and 1 Z2000 EMU, Luxembourg (50 Hz)

1 OTU EMU, test track in Västerås (artificial ice, 16.7 and 50 Hz)

1 Class 357 EMU, test track in Cerhenice (simulated ice test, 50 Hz)

Lars Buhrkall, Sviegade 3, DK - 6760 Ribe. Tel. +45 74846011, Email lars@buhrkall.dk, www.buhrkall.dk

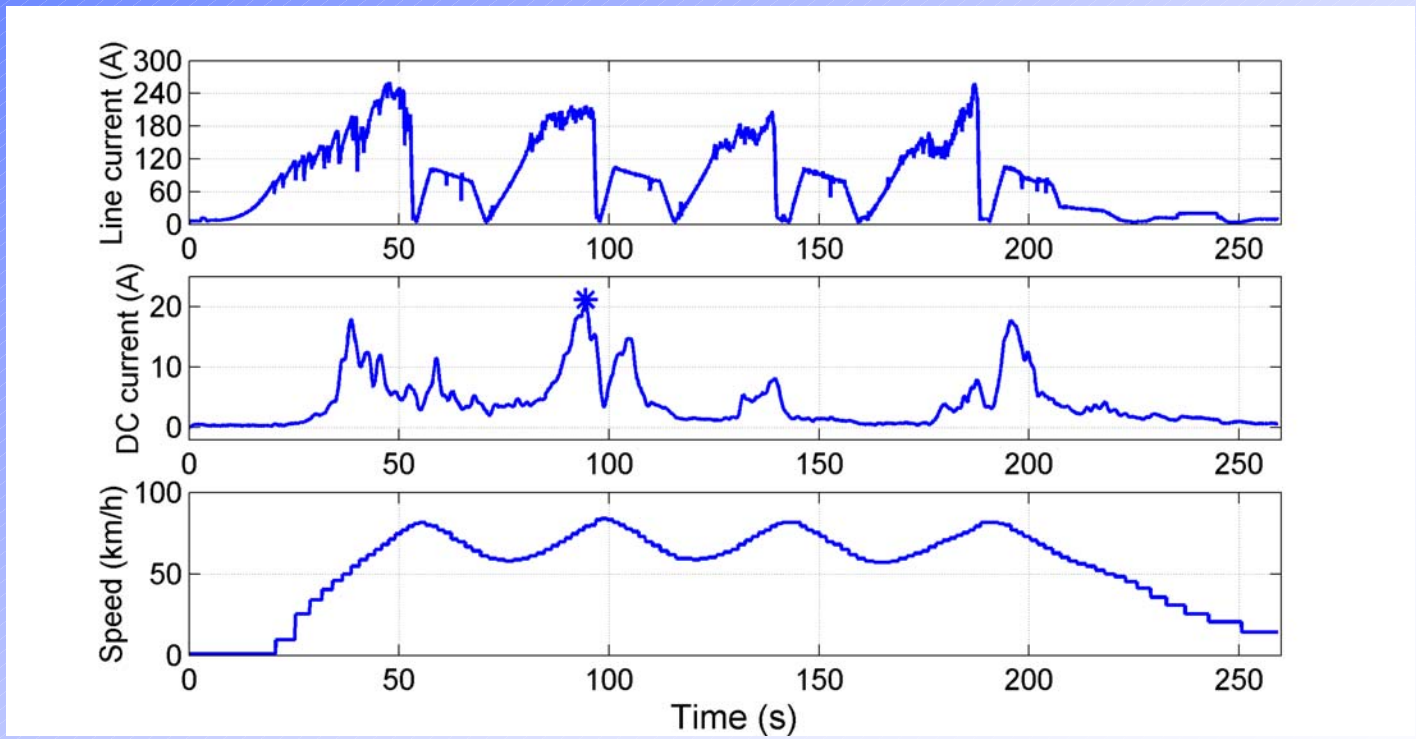
Analysis of field data

- Correlations between the DC level and other variables (speed, power, cos(ø), THD, signal interference)
- DC levels at multiple operation, current split between vehicles
- What is DC – comparison between analysis methods

Lars Buhrkall, Sviegade 3, DK - 6760 Ribe. Tel. +45 74846011, Email lars@buhrkall.dk, www.buhrkall.dk

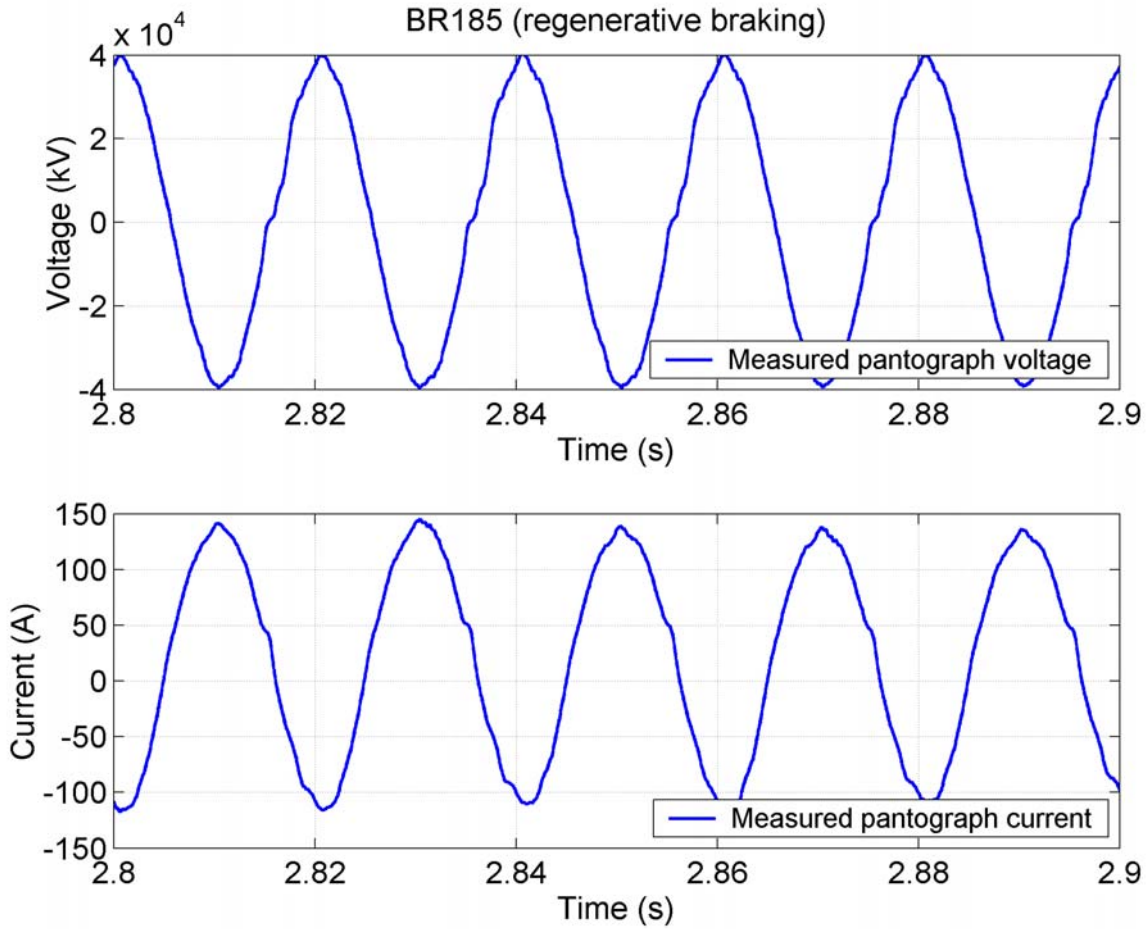
BR185, single loco tests

- 9 tests with ice, Luxembourg – Troisvierges
- Total distance ≈ 34 km, max. speed ≈ 90 km/h, stops each 3-6 km, total time ≈ 39 min.



Lars Buhrkall, Sviegade 3, DK - 6760 Ribe. Tel. +45 74846011, Email lars@buhrkall.dk, www.buhrkall.dk

Typical waveforms, BR185 tests



15 A DC steadily for 10 s and more

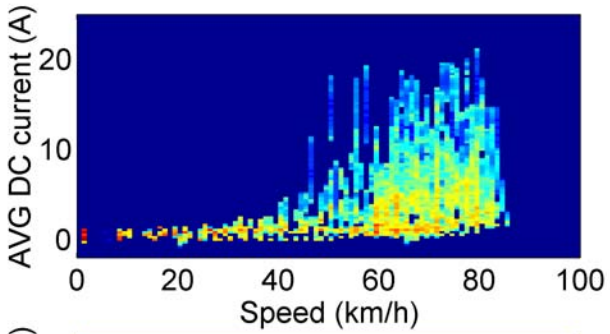
Lars Buhrkall, Sviegade 3, DK - 6760 Ribe. Tel. +45 74846011, Email lars@buhrkall.dk, www.buhrkall.dk

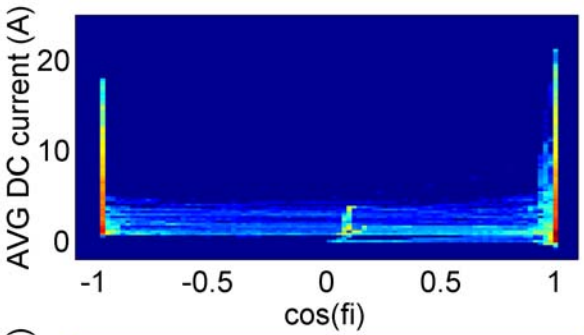
Summary, BR185 single loco

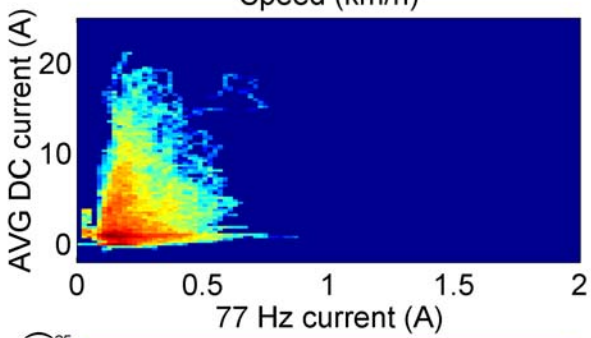
BR185 in Luxembourg

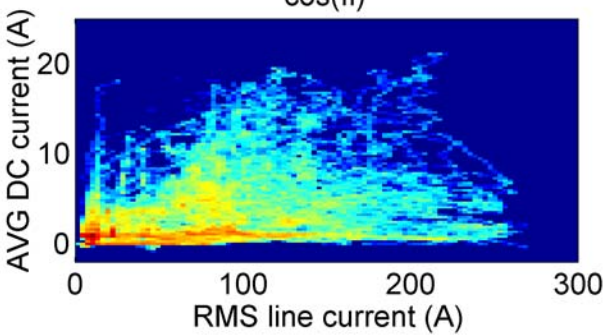
Analysis of test results, BR185

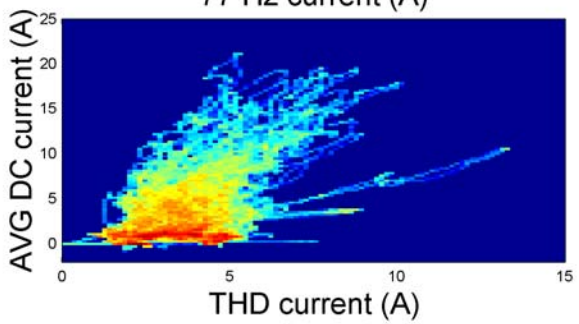
Test date: 09-Dec-2001
Rev. 1, 06-Jun-2002 Analysis: LB, 30-Oct-2003











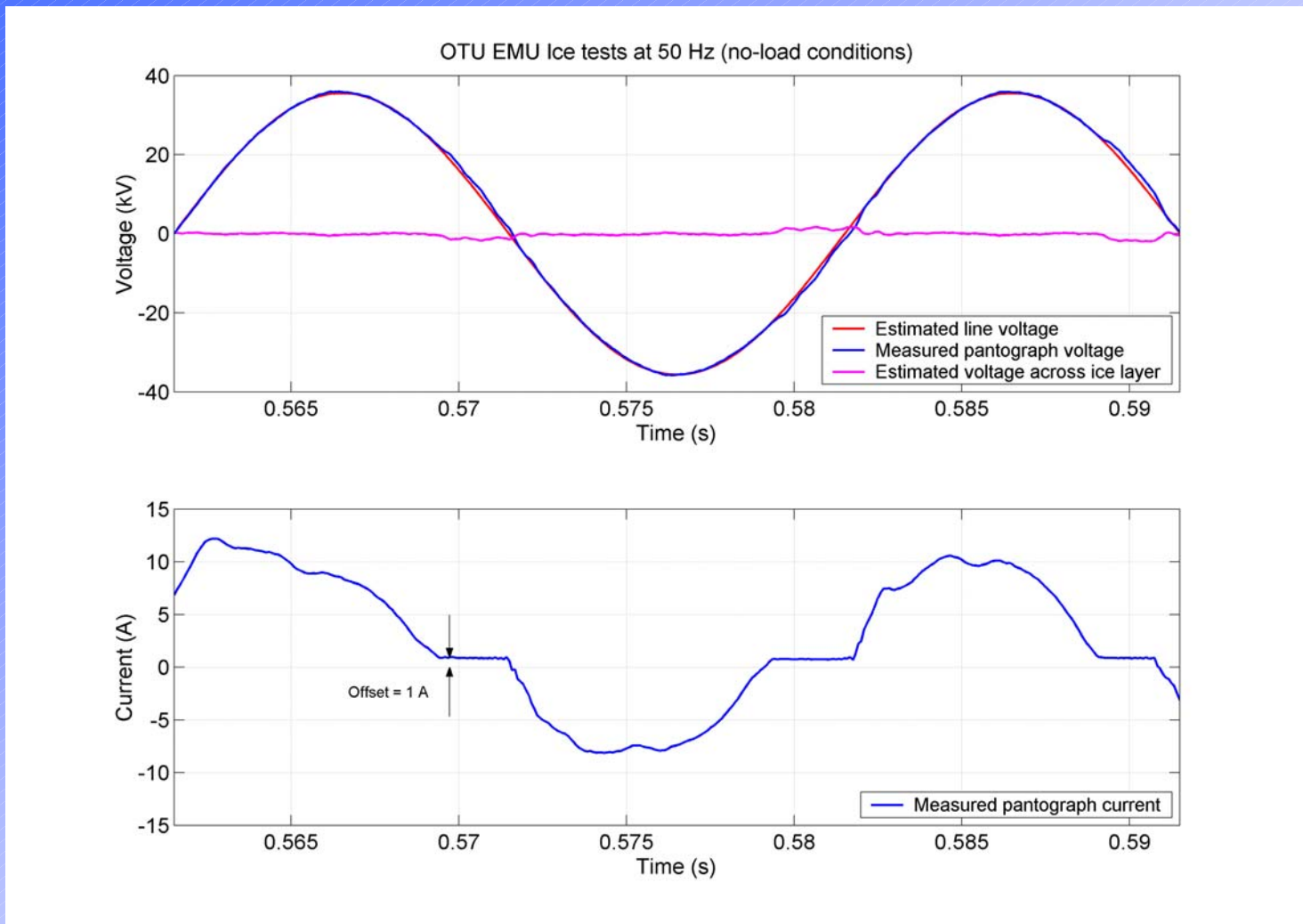
Lars Buhrkall, Sviegade 3, DK - 6760 Ribe. Tel. +45 74846011, Email lars@buhrkall.dk, www.buhrkall.dk

OTU tests

- 50 m OHL sprayed with water at T ≈ -2°C.
- 24 tests at 16 2/3 Hz, all at low power:
  - 18 tests with normal parameters
  - 6 tests with increased reactive current reference.
- 22 tests at 50 Hz:
  - 6 at low power, normal parameters
  - 6 at low power, incr. reactive current
  - 10 at higher power, normal parameters

Lars Buhrkall, Sviegade 3, DK - 6760 Ribe. Tel. +45 74846011, Email lars@buhrkall.dk, www.buhrkall.dk

Typical waveforms, OTU tests



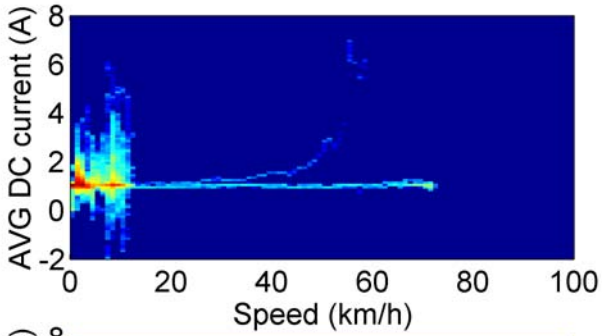
Lars Buhrkall, Sviegade 3, DK - 6760 Ribe. Tel. +45 74846011, Email lars@buhrkall.dk, www.buhrkall.dk

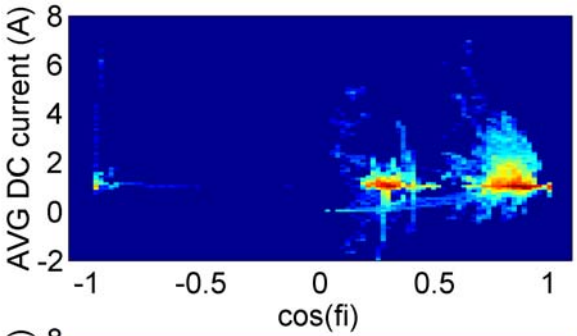
Summary 16 2/3 Hz OTU tests

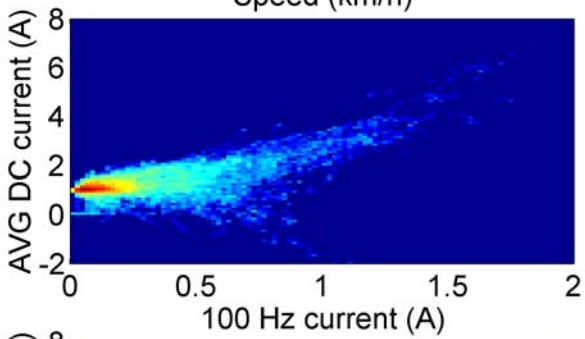
Ice tests with the OTU EMU

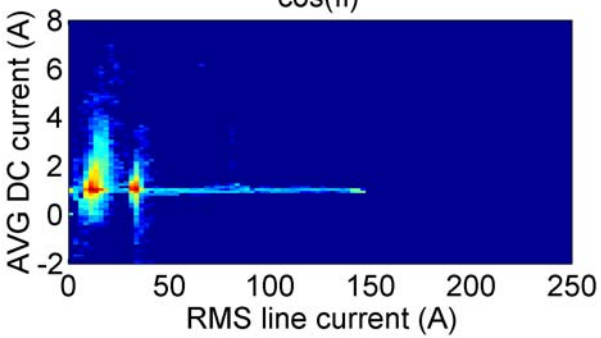
Analysis of test results, 16 Hz tests

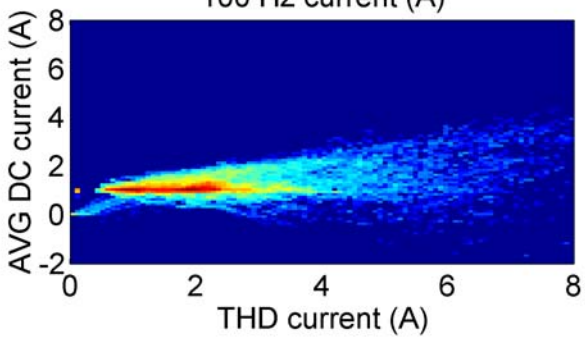
Test date: 23-Mar-2002
Rev. 1, 06-Jun-2002 Analysis: LB, 07-Jun-2002







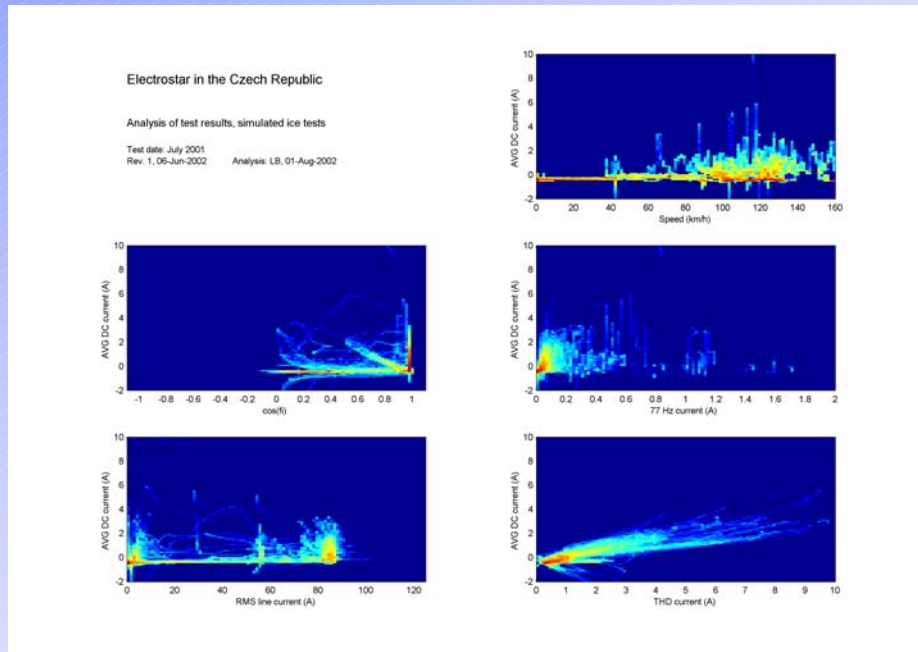




Lars Buhrkall, Sviegade 3, DK - 6760 Ribe. Tel. +45 74846011, Email lars@buhrkall.dk, www.buhrkall.dk

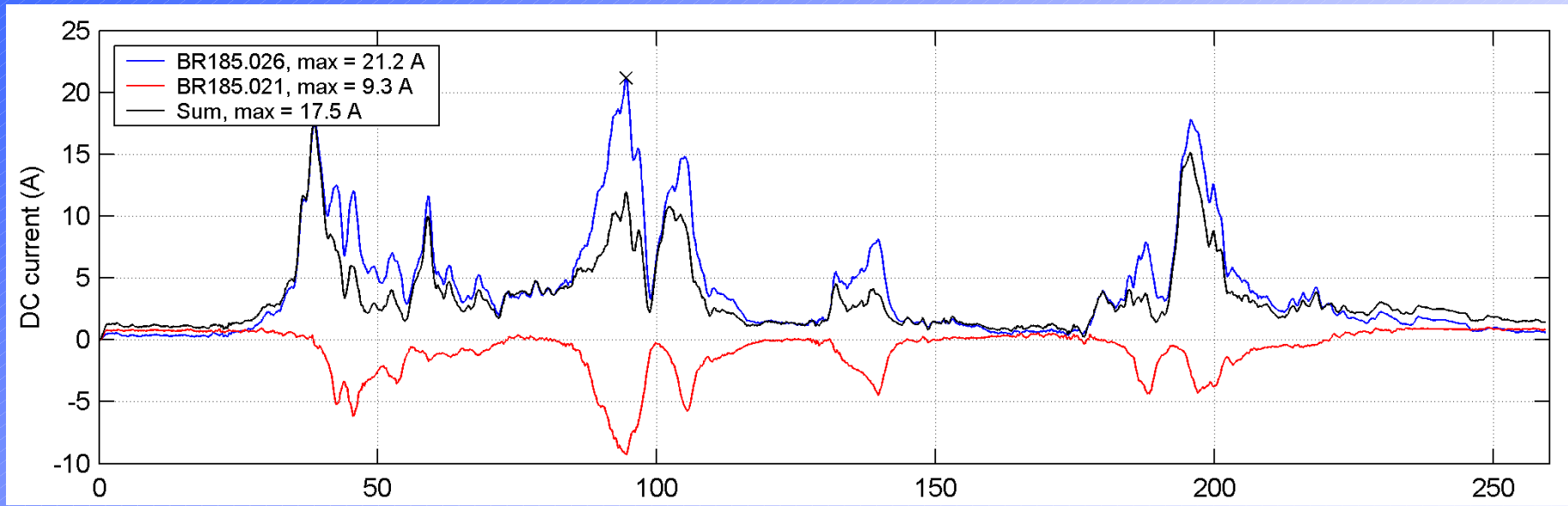
Class 357 in Cerhenice

- Simulated ice test, reduced pantograph air pressure creating significant arcing
- Not equal to real ice conditions, but good enough to test the performance of the vehicle



Lars Buhrkall, Sviegade 3, DK - 6760 Ribe. Tel. +45 74846011, Email lars@buhrkall.dk, www.buhrkall.dk

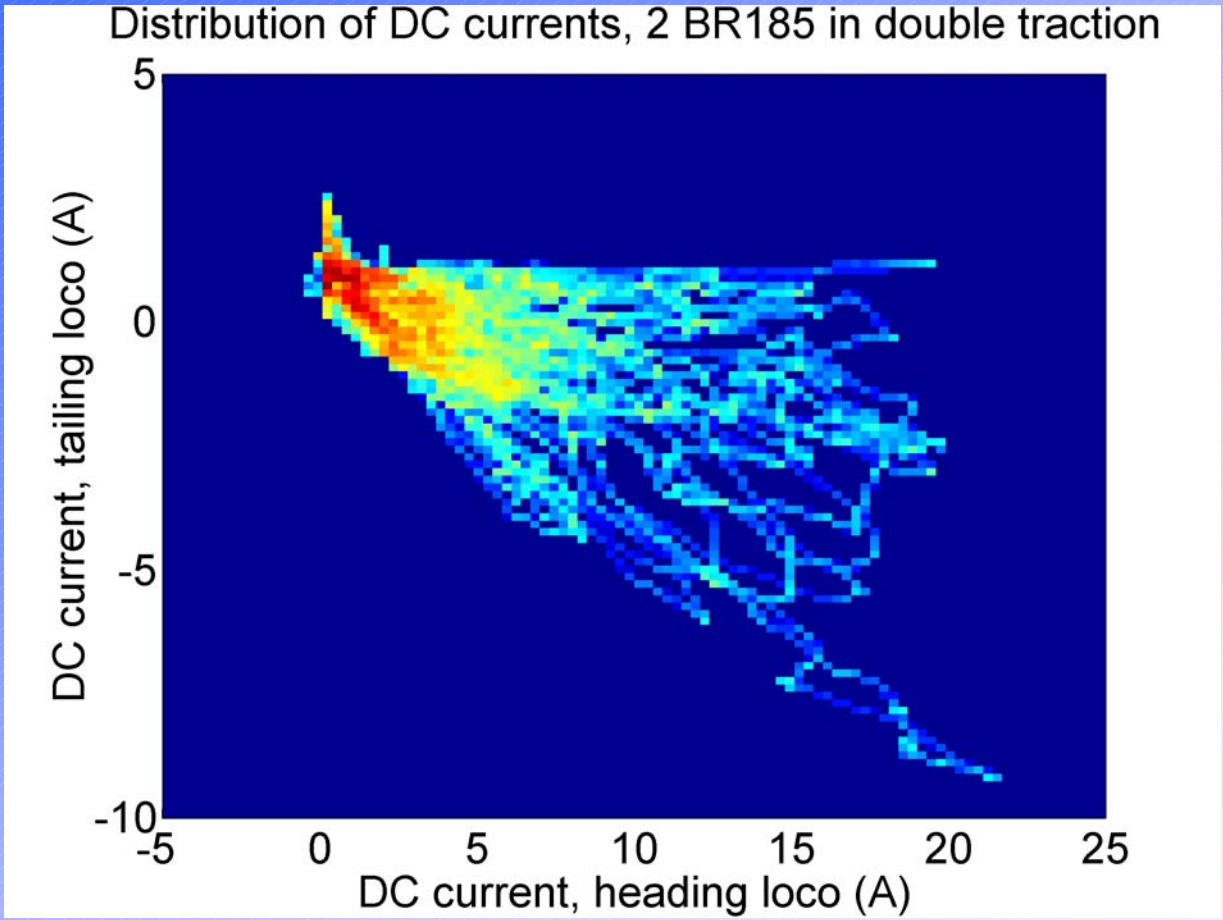
DC currents, 2 BR185s in double traction



- 5 runs ≈ 4 km each, max. speed ≈ 80 km/h
- The heading loco (blue curve) is the generator, the tailing loco (red) return path.
- The total DC (black curve) is generally less that the level from the heading loco.

Lars Buhrkall, Sviegade 3, DK - 6760 Ribe. Tel. +45 74846011, Email lars@buhrkall.dk, www.buhrkall.dk

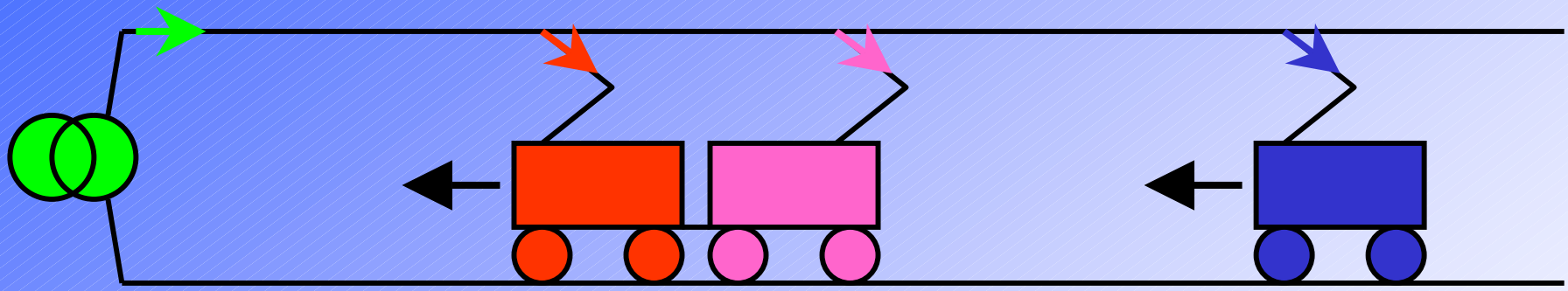
Current split, 2 BR185



Between 0 % and 50 % of the DC that is generated by the heading loco returns via the tailing loco

Lars Buhrkall, Sviegade 3, DK - 6760 Ribe. Tel. +45 74846011, Email lars@buhrkall.dk, www.buhrkall.dk

2 BR185, Z2000, and substation

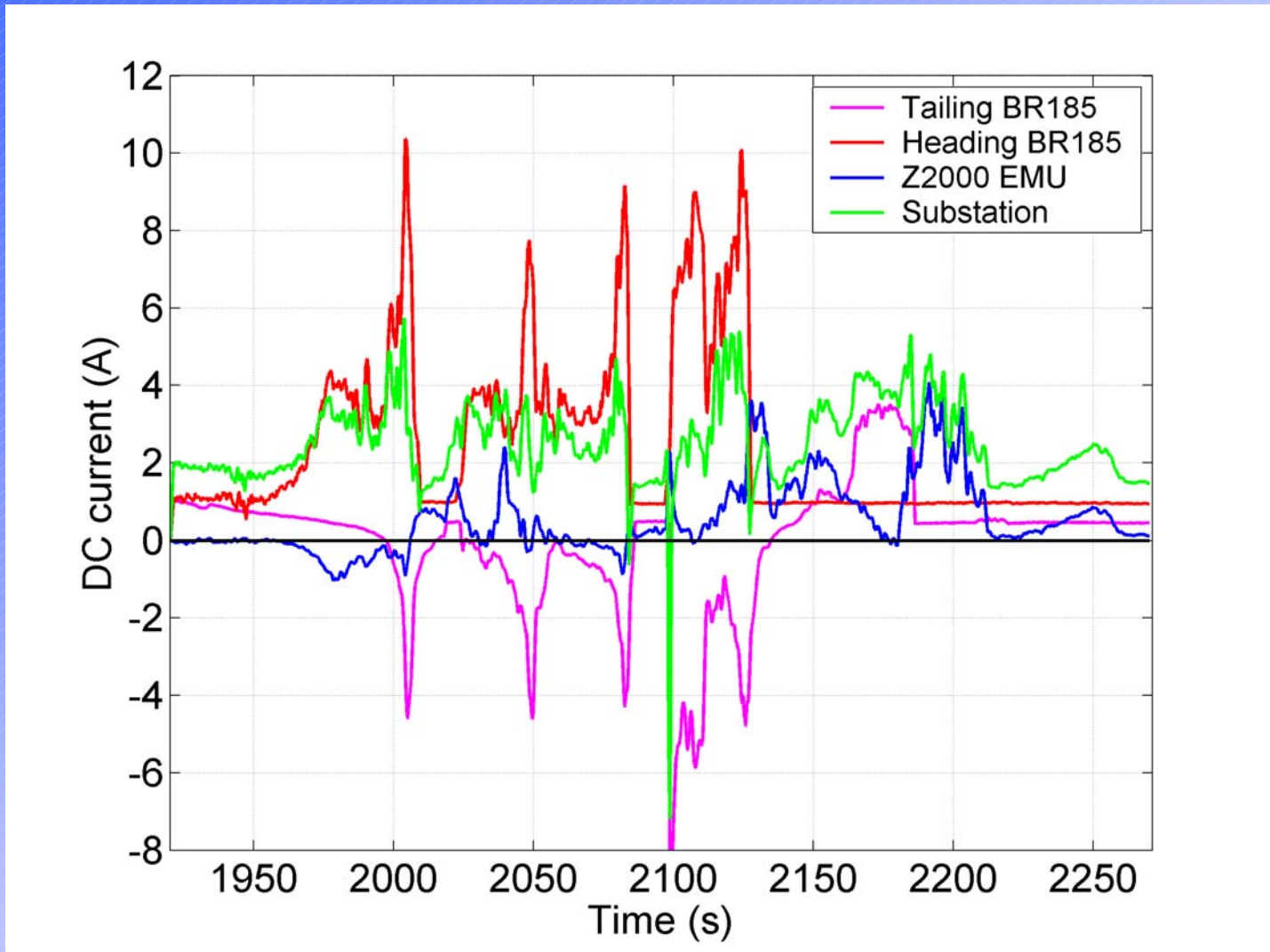


Substation 2 BR185 locos 1 Z2000 EMU

- Total line section length 36 km, 25 kV 50 Hz
- 2 BR185 locos (AC-motors) in multiple in the middle
- 1 Z2000 EMU (DC-motors) at the end
- Current transducers in all vehicles and in the substation

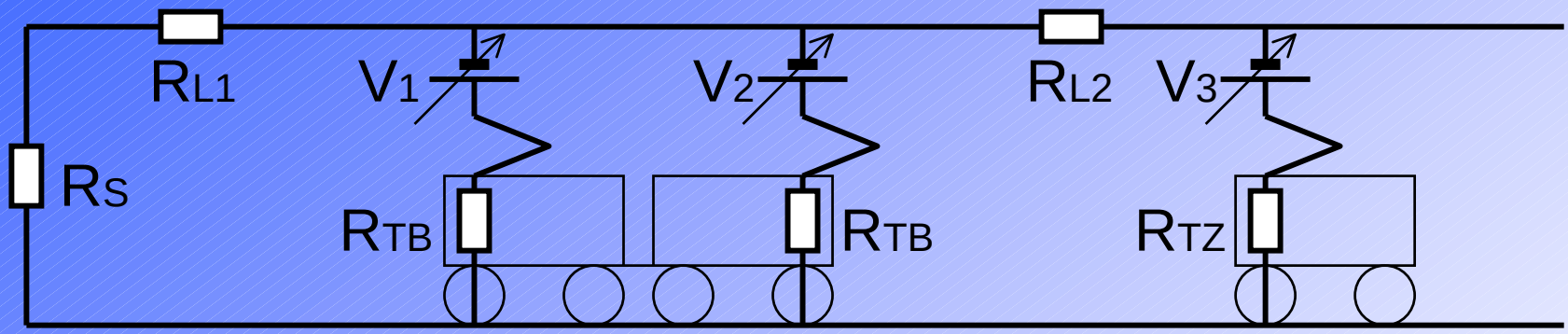
Lars Buhrkall, Sviegade 3, DK - 6760 Ribe. Tel. +45 74846011, Email lars@buhrkall.dk, www.buhrkall.dk

DC current split, 3 trains and substation



Lars Buhrkall, Sviegade 3, DK - 6760 Ribe. Tel. +45 74846011, Email lars@buhrkall.dk, www.buhrkall.dk

Circuit model for DC

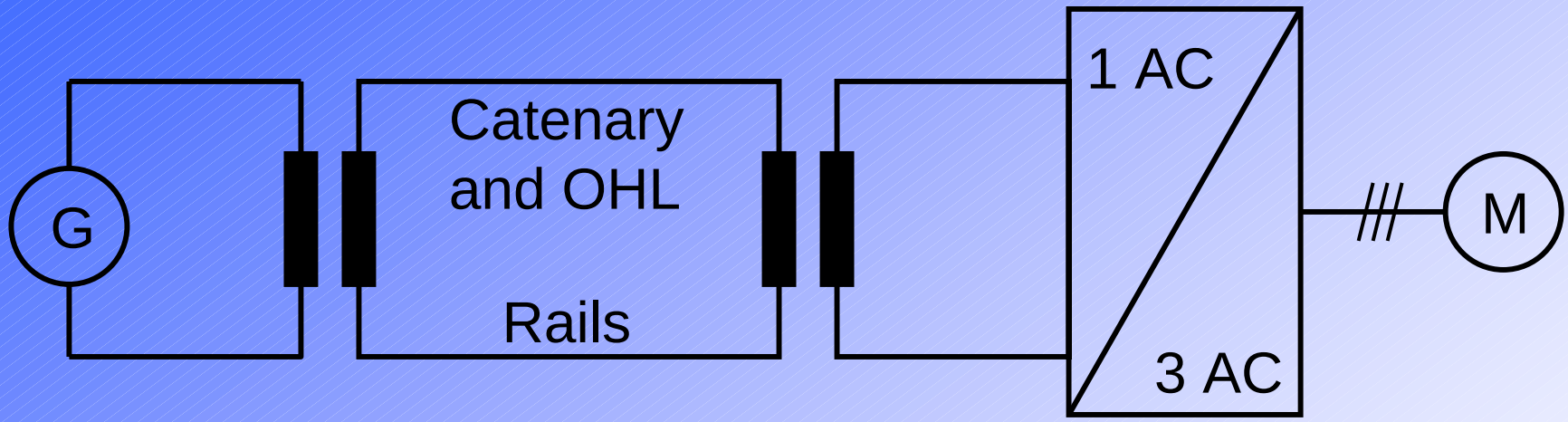


Substation 2 BR185 locos 1 Z2000 EMU

- Each OHL-pantograph interface is a voltage source 0-20 V DC (up to 100 V DC at severe ice conditions)
- The distribution of DC currents is determined by the resistances in the transformers and the OHL and return current system

Lars Buhrkall, Sviegade 3, DK - 6760 Ribe. Tel. +45 74846011, Email lars@buhrkall.dk, www.buhrkall.dk

Alternative DC generators?



Power system and substation transformer

Vehicle with main transformer, converter systems, and motors

- 3 galvanically separated circuit loops
- No other ice-related DC source in the OHL loop
- Transformers do not transfer steady DC
- Induced currents? *(northern light, separated tracks)*

Lars Buhrkall, Sviegade 3, DK - 6760 Ribe. Tel. +45 74846011, Email lars@buhrkall.dk, www.buhrkall.dk

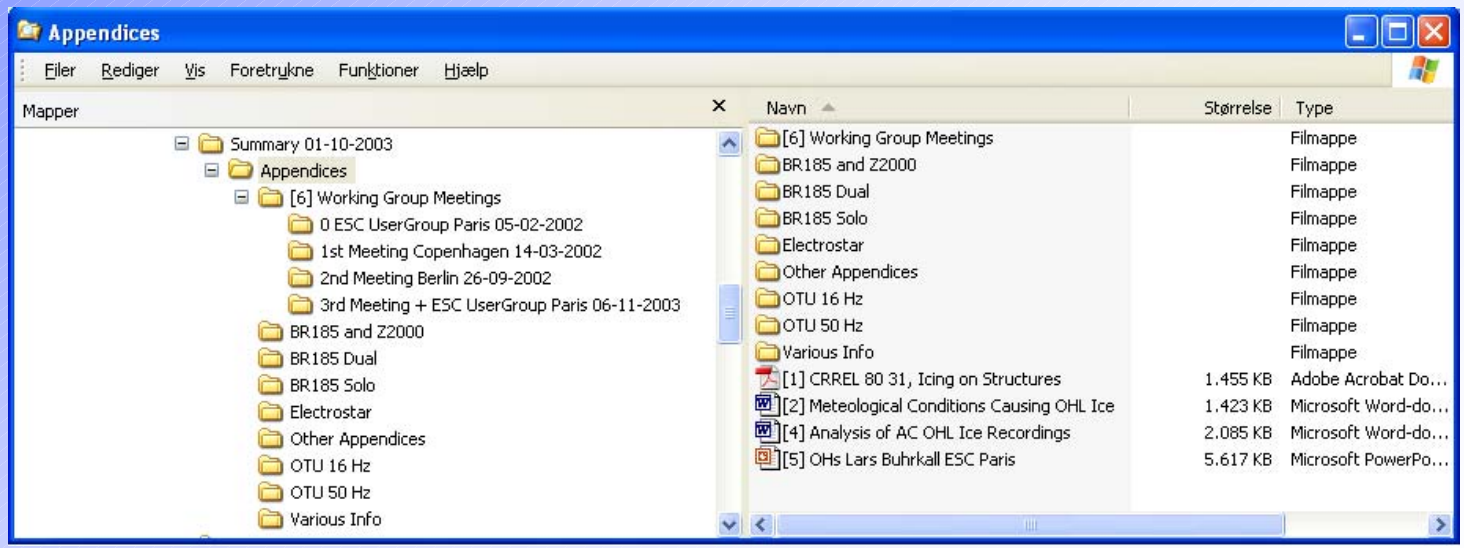
Conclusions

- Copper + carbon + arc $\Rightarrow$ DC voltage source at the OHL-pantograph interface
- Normally up to 20 V DC, but up to 100 V DC at severe ice conditions
- The DC currents cause even harmonics
- Multiple operation does not generally increase the DC *(parallel voltage sources!)*
- Full agreement between the arc theory and the lab and field test results

Lars Buhrkall, Sviegade 3, DK - 6760 Ribe. Tel. +45 74846011, Email lars@buhrkall.dk, www.buhrkall.dk

Information in the ESC InfoBank

- Summary report
- Reports on meteorological conditions
- Analysis of data from field measurements
- Team meetings (minutes and notes)
- OH's
- Etc.



Lars Buhrkall, Sviegade 3, DK - 6760 Ribe. Tel. +45 74846011, Email lars@buhrkall.dk, www.buhrkall.dk

Thanks to:

- All in the OHL Ice Team
- CFL, DB Cargo, and DSB for the usage of the BR185 data

Lars Buhrkall, Sviegade 3, DK - 6760 Ribe. Tel. +45 74846011, Email lars@buhrkall.dk, www.buhrkall.dk