The 1983 and 2003 Blackouts in Sweden

Nordic Electric Power System Seminar Chalmers
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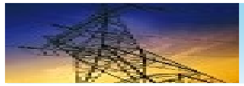
Presentation Outline



- Introduction to DNV and to myself
- Notification of the Hagby Disturbance - 7 Second Fault
- Swedish disturbance 1983-12-27
- Swedish disturbance 2003-09-23
- Concluding remarks

DNV - An Energy Technology Power House

- Established in 1864 – Det Norske Veritas
- A foundation focused on
  - **Classification** - Maritime, Oil & Gas
  - **Certification** – ISO standards
  - **Energy Systems**
    - Generation, Transmission, Distribution and use of Electric Energy
- Investing 5% of the annual revenues in research, development and innovation activities
- Main office in Oslo
- Main Energy hub in Arnhem, Netherlands
- About 20 electrical engineers in Sweden – Gothenburg, Malmö, and Stockholm

2000 experts

Largest independent technical advisor for renewable energy, transmission, distribution and use

>25

standards and guidelines published as a leading certification body

No. 1

in smart grid testing with laboratories in Arnhem, Madrid and Singapore

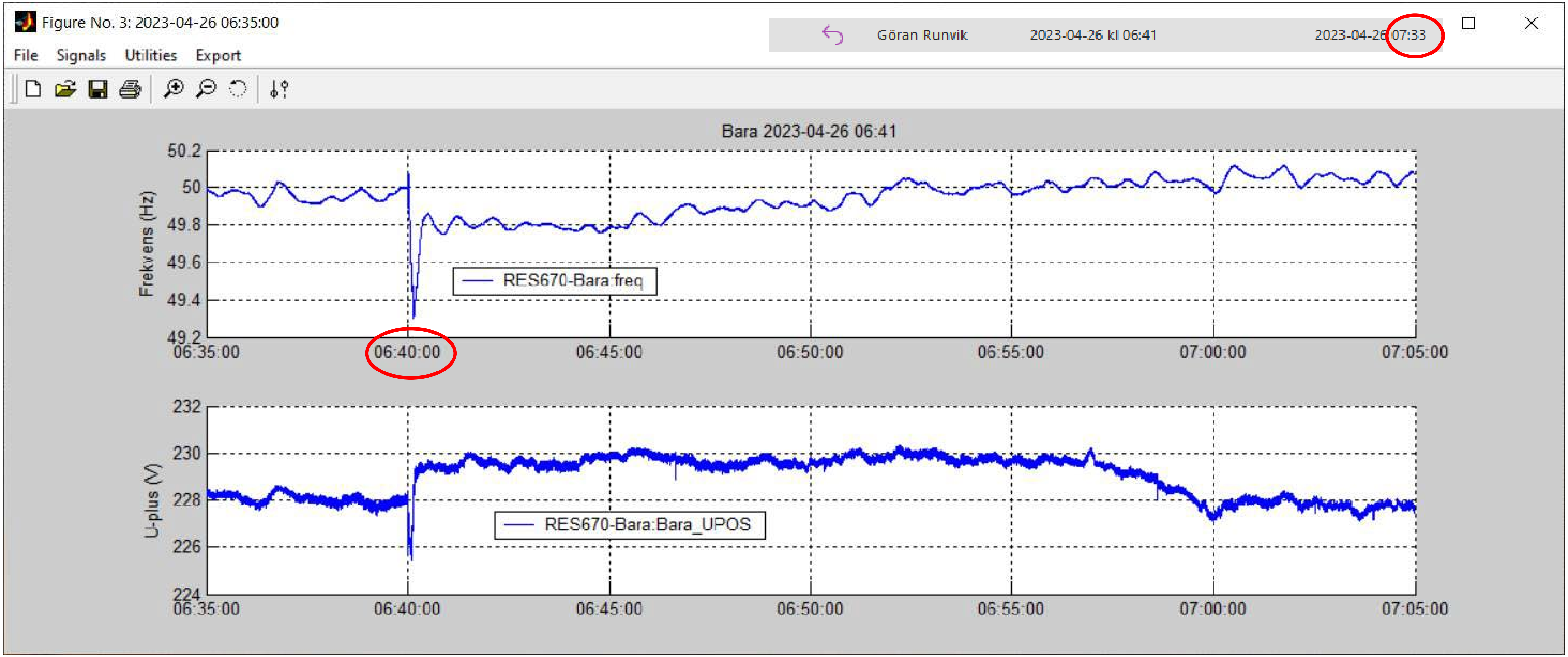
90 years

experience in the power industry, incl. 40 years in wind and energy management and 20 years in solar

Personal Introduction

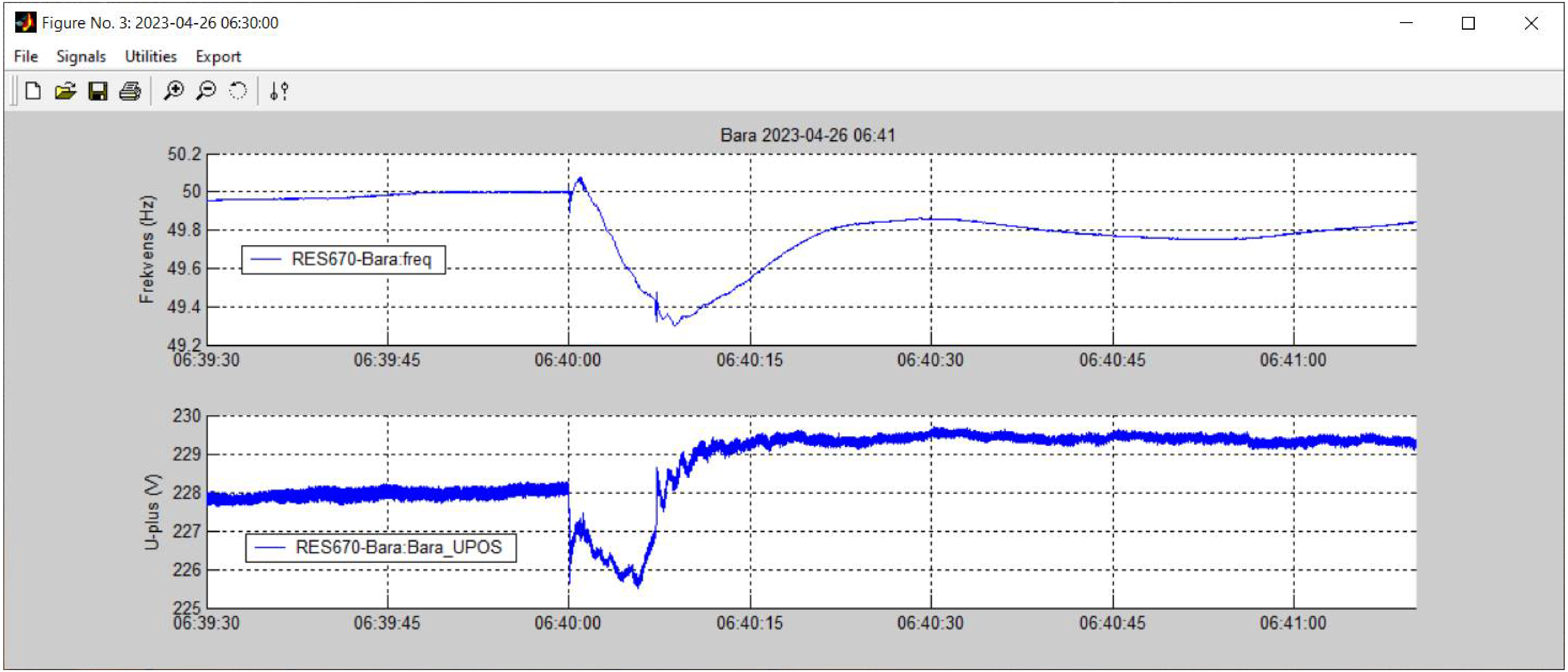
- Daniel Karlsson
- Senior Principal Engineer, DNV Energy Systems
- Major experiences
  - Power system analysis
  - Power system protection
  - Wide area protection (SPS / SIPS / PMUs)
  - Utility and manufacturer background
    - Sydkraft (now E.ON)
    - ABB (now Hitachi)
    - Gothia Power
    - DNV
  - Academic background
    - Chalmers University of Technology

Hagby 220 kV fault – First notice – A PMU outside Malmö (600 km from Hagby)



- Observations? – With respect to frequency / voltage? - Duration?

Hagby 220 kV fault – First notice – A closer look



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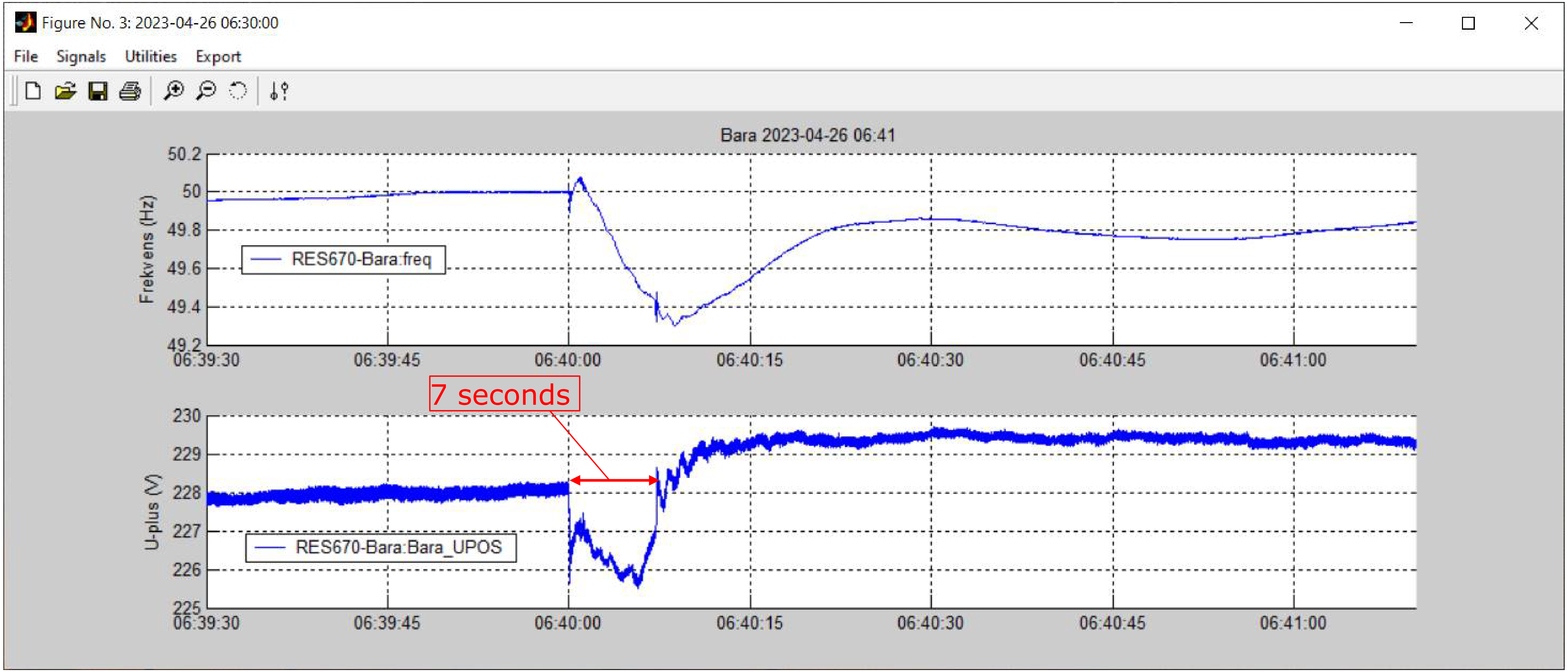
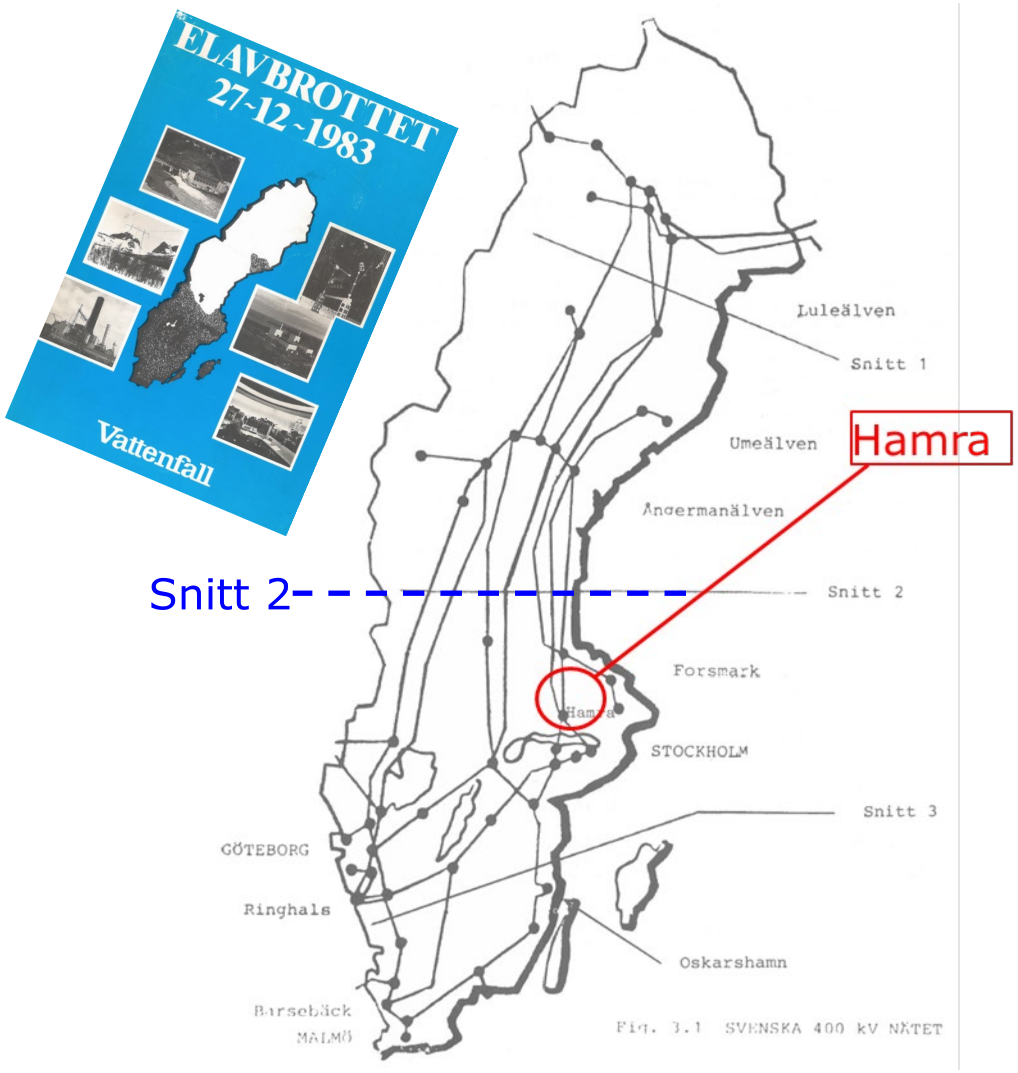
Hagby 220 kV fault – First notice – A closer look



- If you know what you are looking for – You can see the 7 seconds!

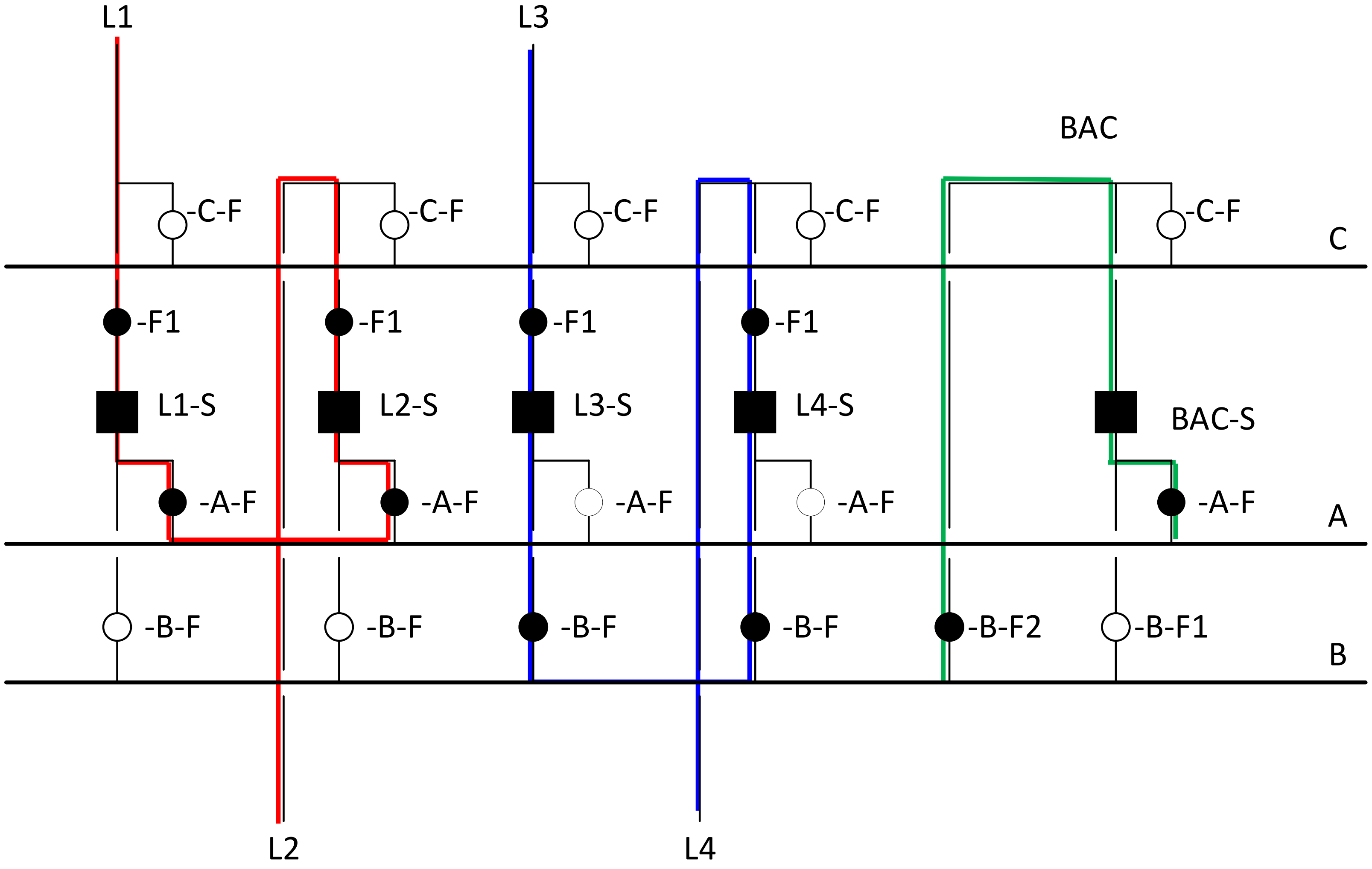
1983-12-27 Swedish National Blackout – 65% of the consumption interrupted

- Preconditions
  - Close to full power transmission from North to South
  - Import from Norway and export to Denmark
  - Total load (in Sweden) 17 000 MW
  - Generation: 64% hydro, 34% nuclear, 2% fossil
  - "Snitt 2" transfer was about 5600 MW (max 6000 MW)
  - Normal voltage and frequency
- Predisturbance events
  - Oskarshamn 1 taken out of operation (12:20)
  - Replaced by hydro from the north and load reduction in the south



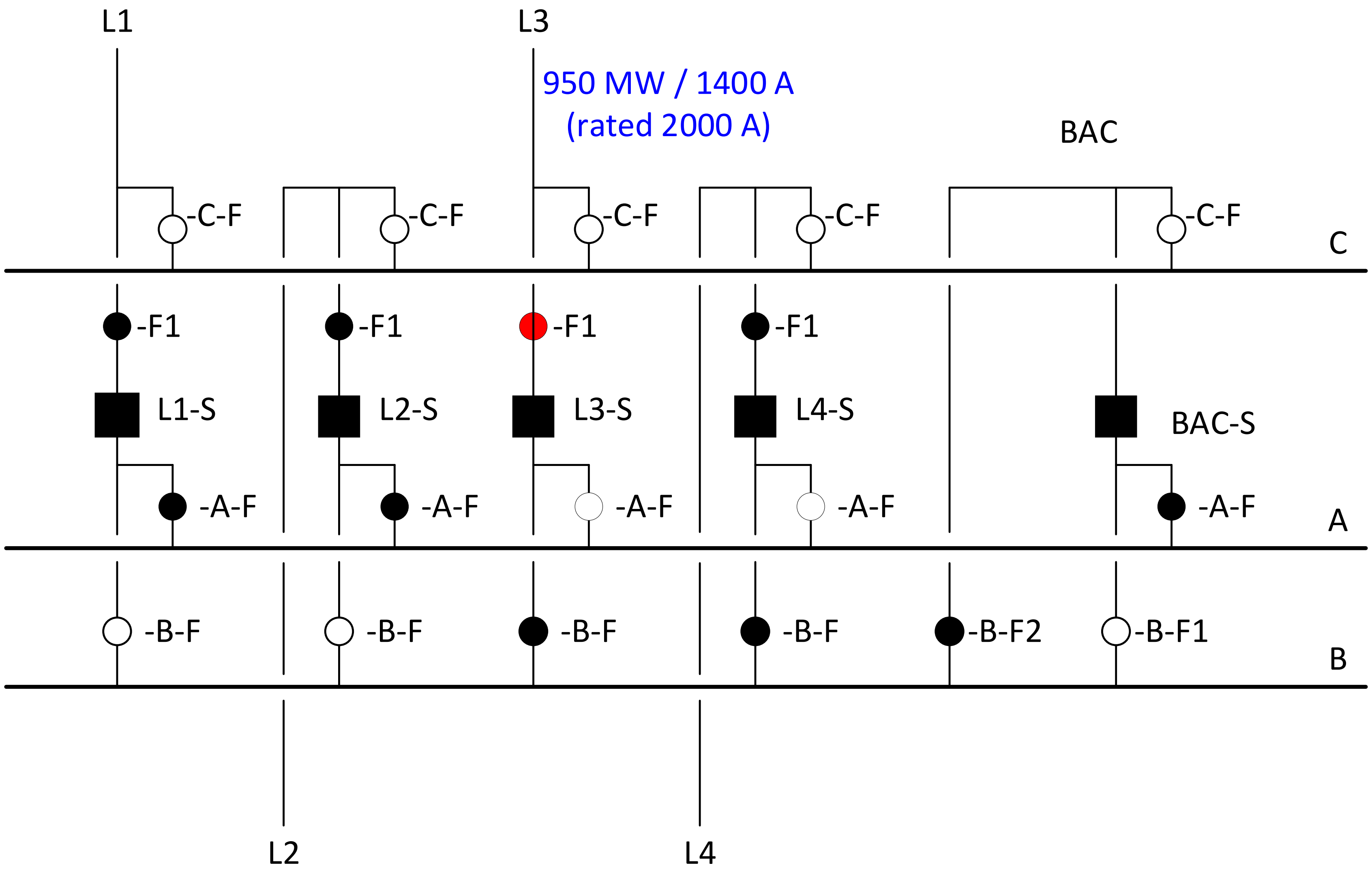
The Hamra substation design – and normal operation switching state

- ABC switchgear
- Combined backup and sectionalizing breaker
- One line from North to the A-bus and one to the B-bus, and similar for the lines southward
  - A busbar fault with successful bus-split will keep one north-south connection alive



12:25 – Overheated disconnector L3-F1 observed

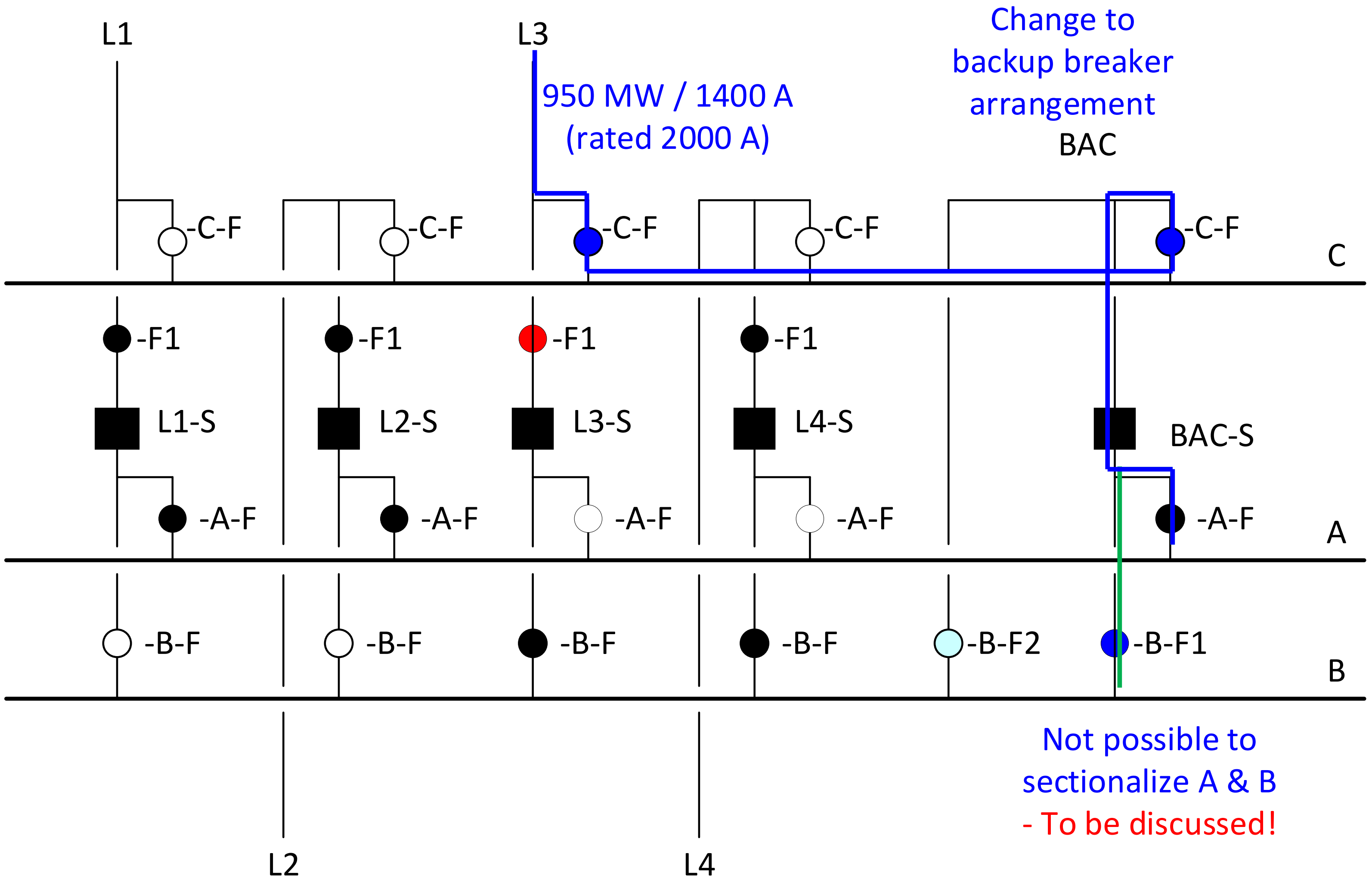
- Overheated due to high resistance – load current less than rated
- Agreed with the control room to immediately take the disconnector out of operation
- Decided to use the backup breaker and firmly connect bus A and bus B



Switching sequence to use the backup breaker for line L3

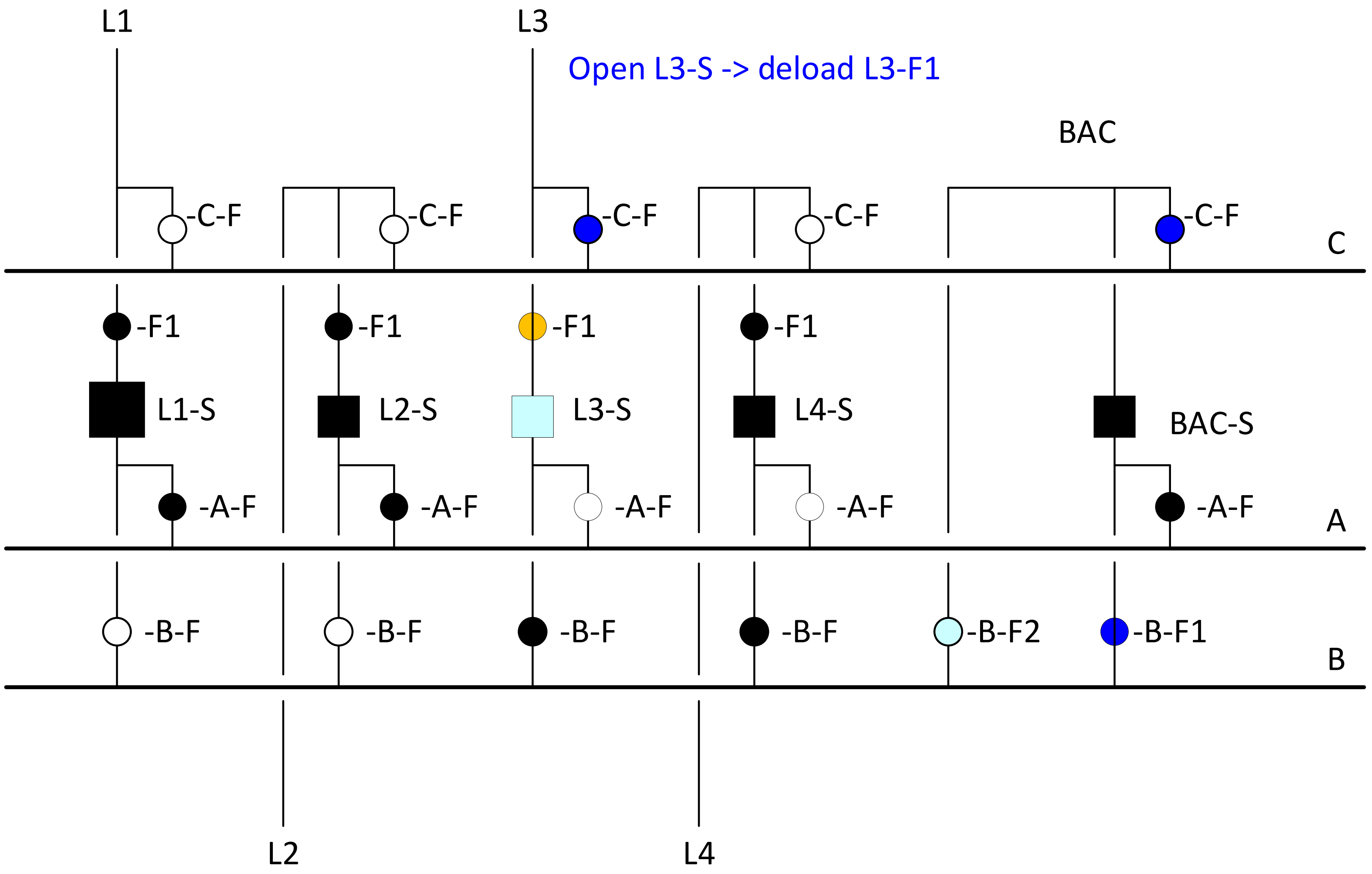
- Connect bus A and bus B via the two disconnectors
  - No sectionalizing possibility!
- Connect L3 to bus A via the bus C and BAC-S

- Strategy to be discussed:
  – Maximum mesh?
  – Pros. & Cons.
  – Ref: [Headline with light image (svk.se)]



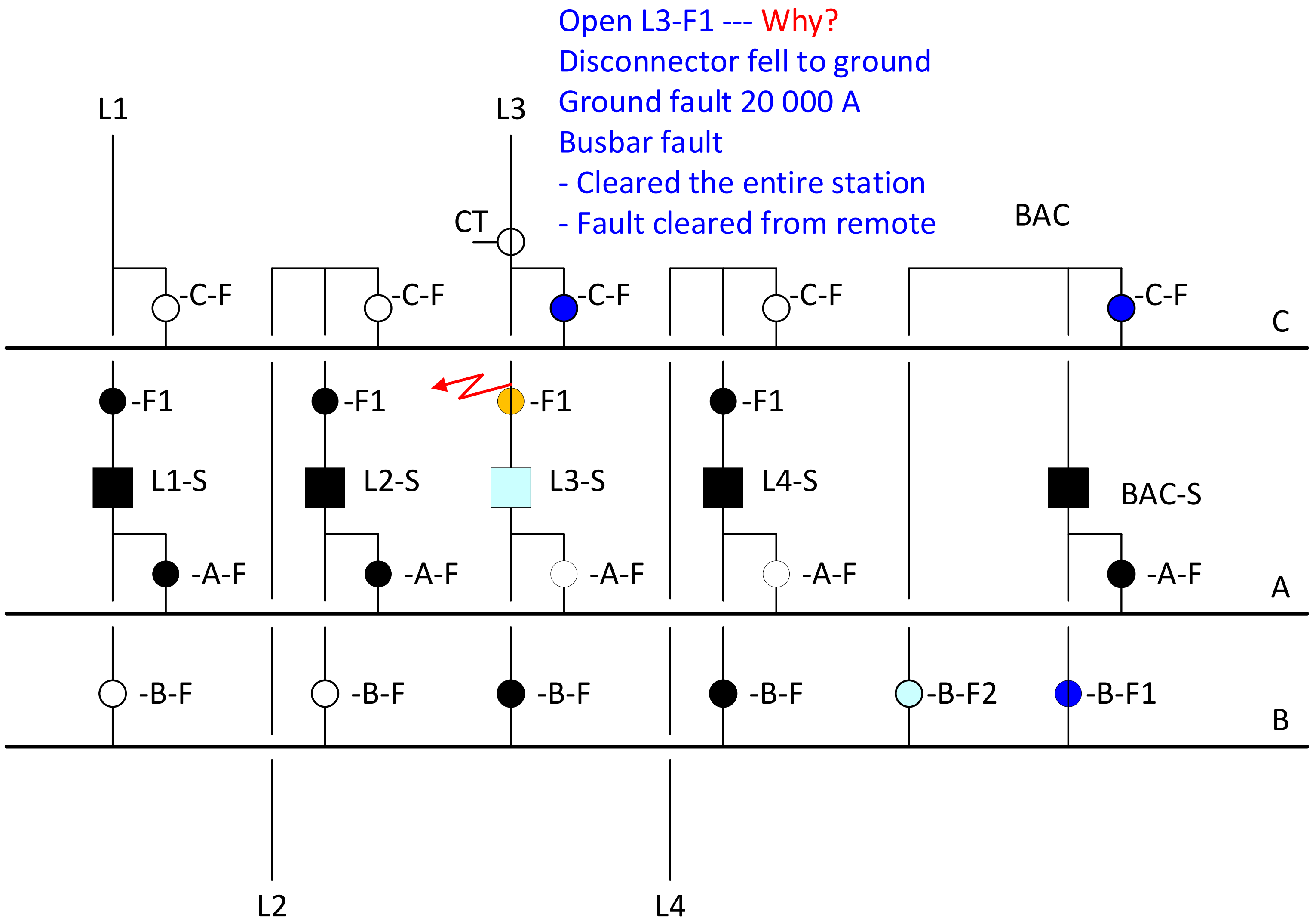
Opening breaker L3-S and deloading the disconnector

- At the end of the switching sequence:
  - L3-S was opened and L3-F1 was totally deloaded (no current)
  - Everything is nice and stable …

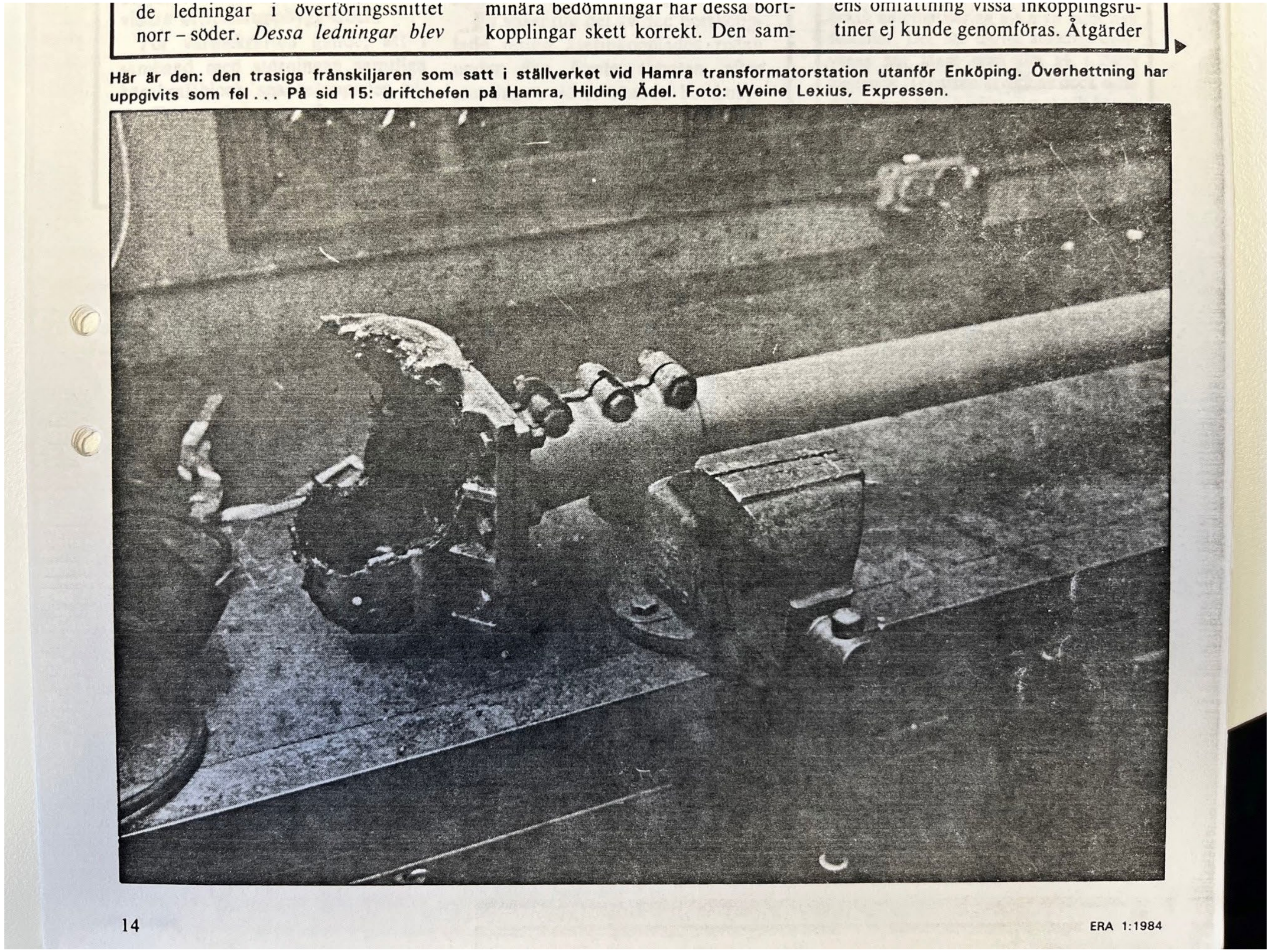


12:57 – The line end / busbar earthfault

- The final stage in the standardized switching sequence:
  - Open the disconnector L3-F1
  - As the disconnector was damaged, it fell apart and caused an earthfault
  - Busbar protection cleared in 3+40 ms (RADSS – Not digital…)



The damaged disconnector in Hamra



de ledningar i överföringssnittet norr – söder. *Dessa ledningar blev*

minära bedömningar har dessa bortkopplingar skett korrekt. Den sam-

ens omfattning vissa inkopplingsrutiner ej kunde genomföras. Åtgärder

Här är den: den trasiga frånskiljaren som satt i ställverket vid Hamra transformatorstation utanför Enköping. Överhettning har uppgivits som fel . . . På sid 15: driftchefen på Hamra, Hilding Ådel. Foto: Weine Lexius, Expressen.

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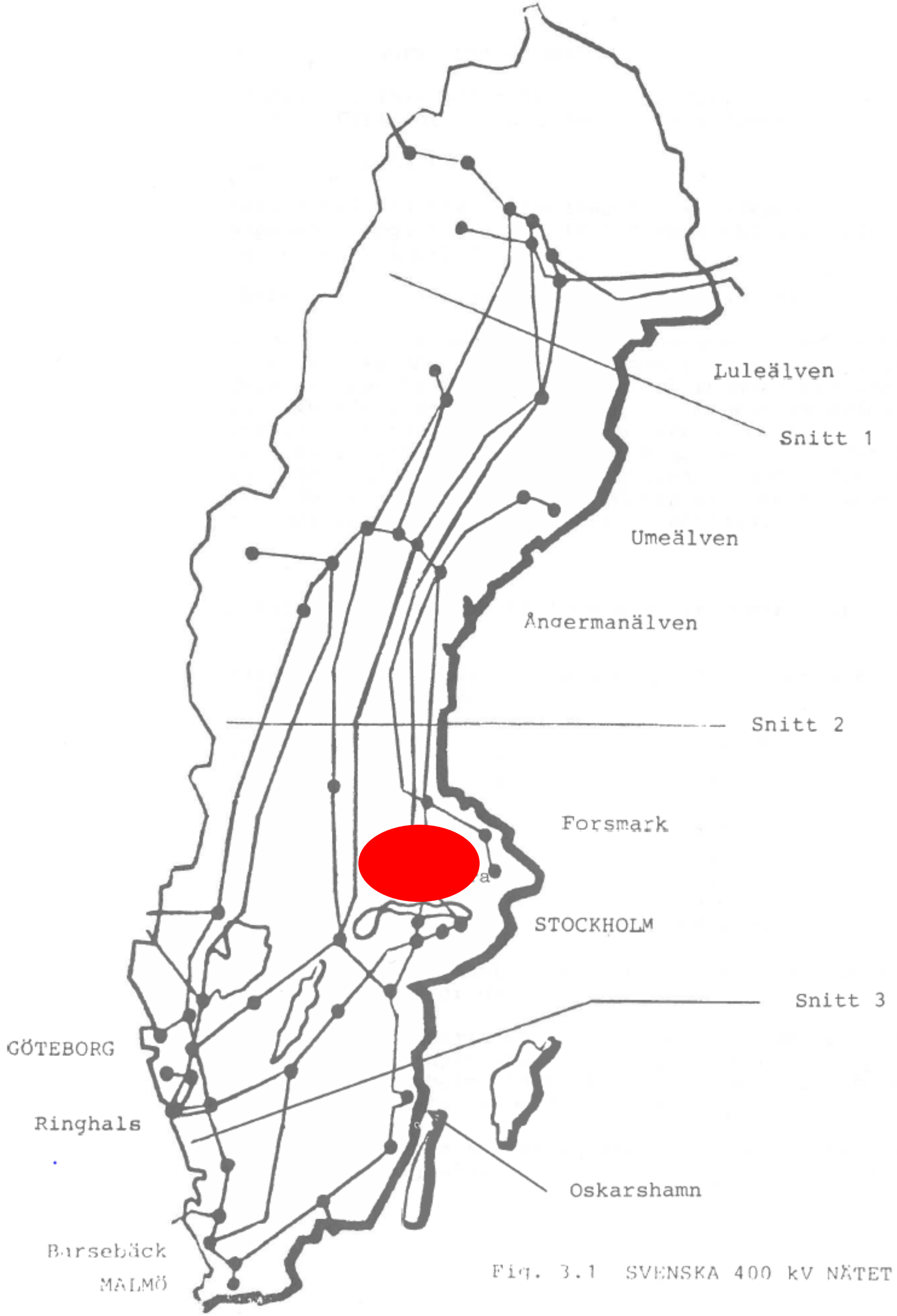
ERA 1:1984

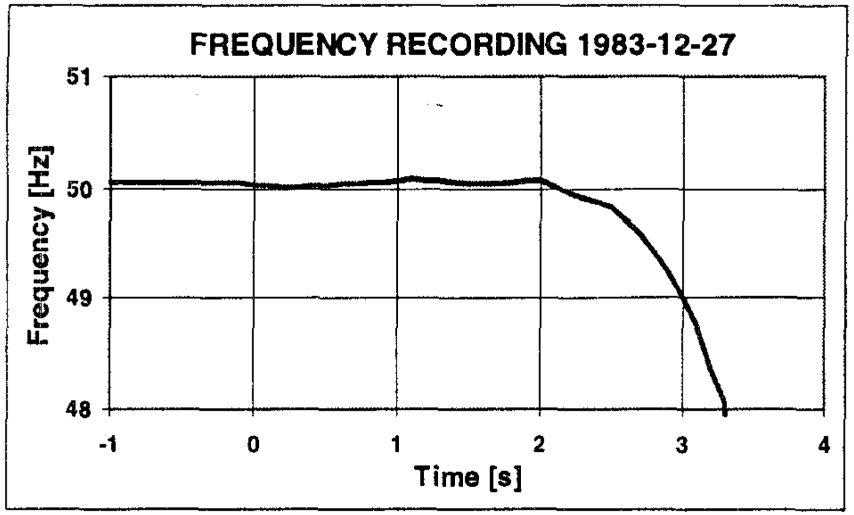
12:57 – A big hole in the transmission network – No loss of generation

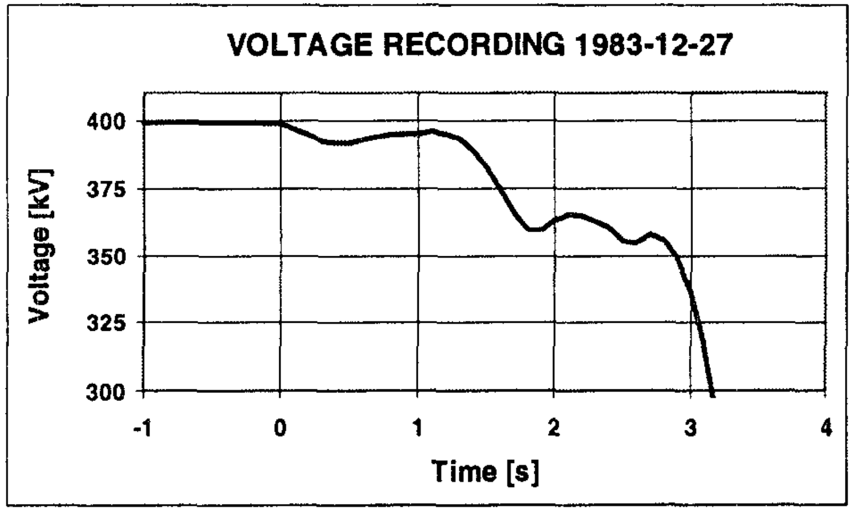
- 2 connections North-South lost
- Important infeed to Stockholm area lost
- No loss of generation
- No change in frequency
- Significantly reduced voltage in mid Sweden
- 6 seconds after the earth-fault a 220 kV line feeding Stockholm tripped due to overload (underimpedance Zone 3)
- Voltages in Southern Sweden kept up by the nuclear generation in Ringhals, Oskarshamn and Barsebäck
- Subsequent voltage reduction in Southern Sweden due to tap-changer stepping and load recovery

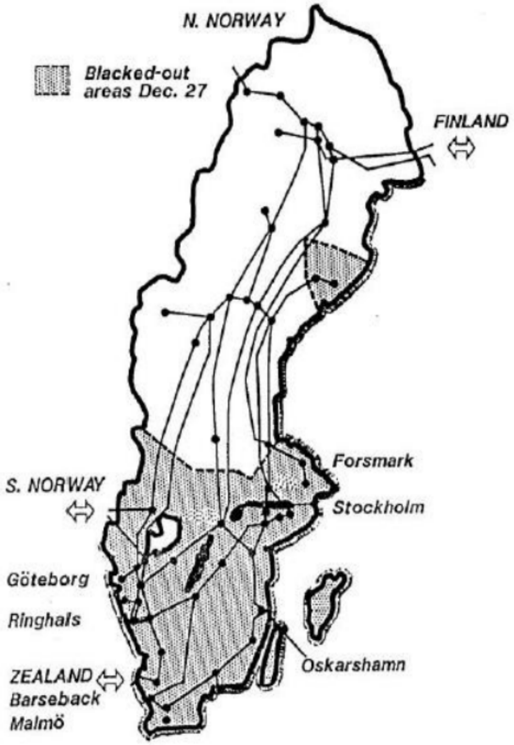


12:58 – Blackout in Southern Sweden

- Stable transmission system voltage and frequency in the very south, close to Barsebäck – See recordings, immediately before the breakdown
- 53 seconds after the earth-fault
  - Distance protection zone 3 finally started to trip lines
- Voltage instability was discovered in Sweden …
- The role of zone 3 in transmission grids to be discussed/investigated

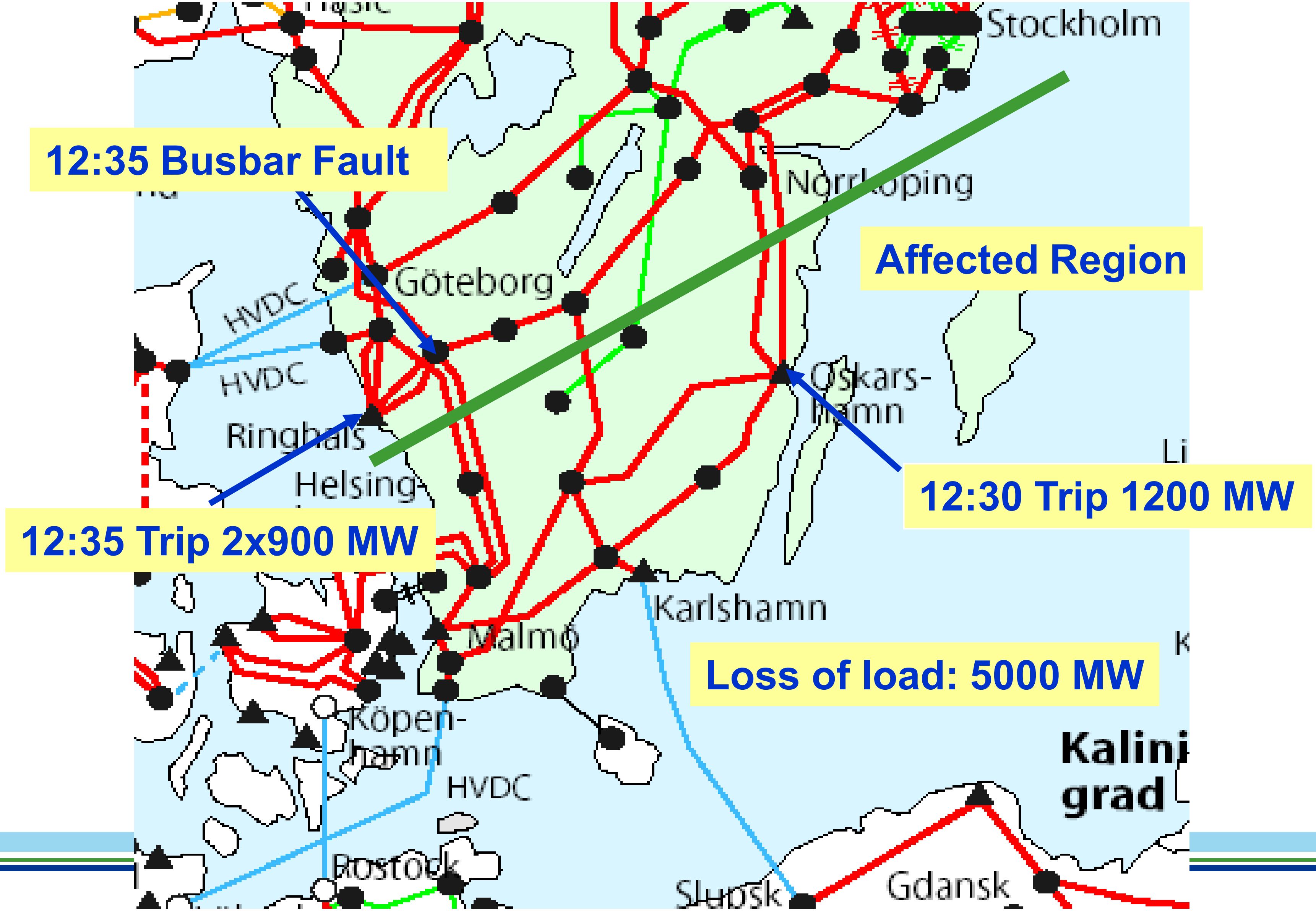


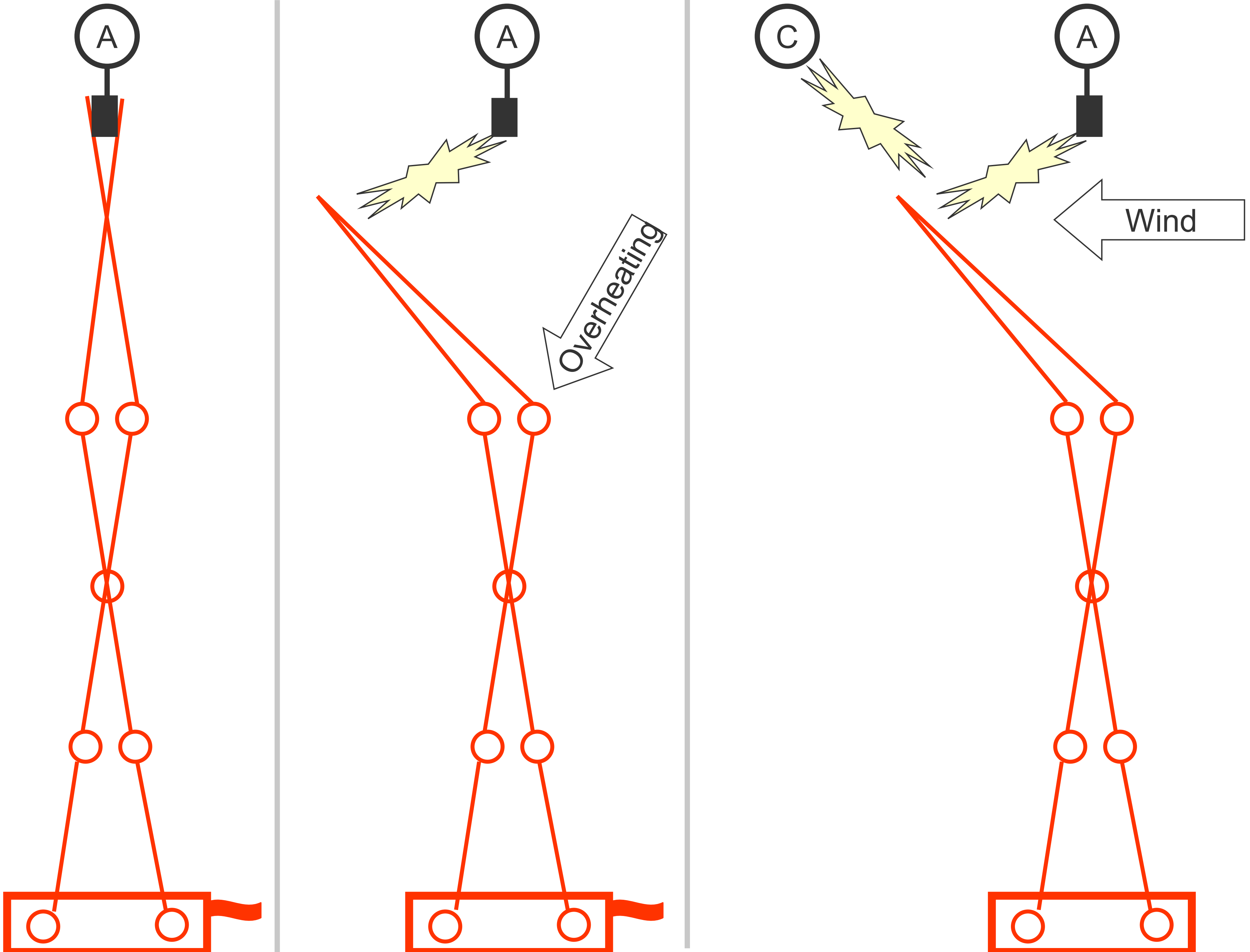




- Ref: [Operational experience of load shedding and new requirements on frequency relays | IET Conference Publication | IEEE Xplore]

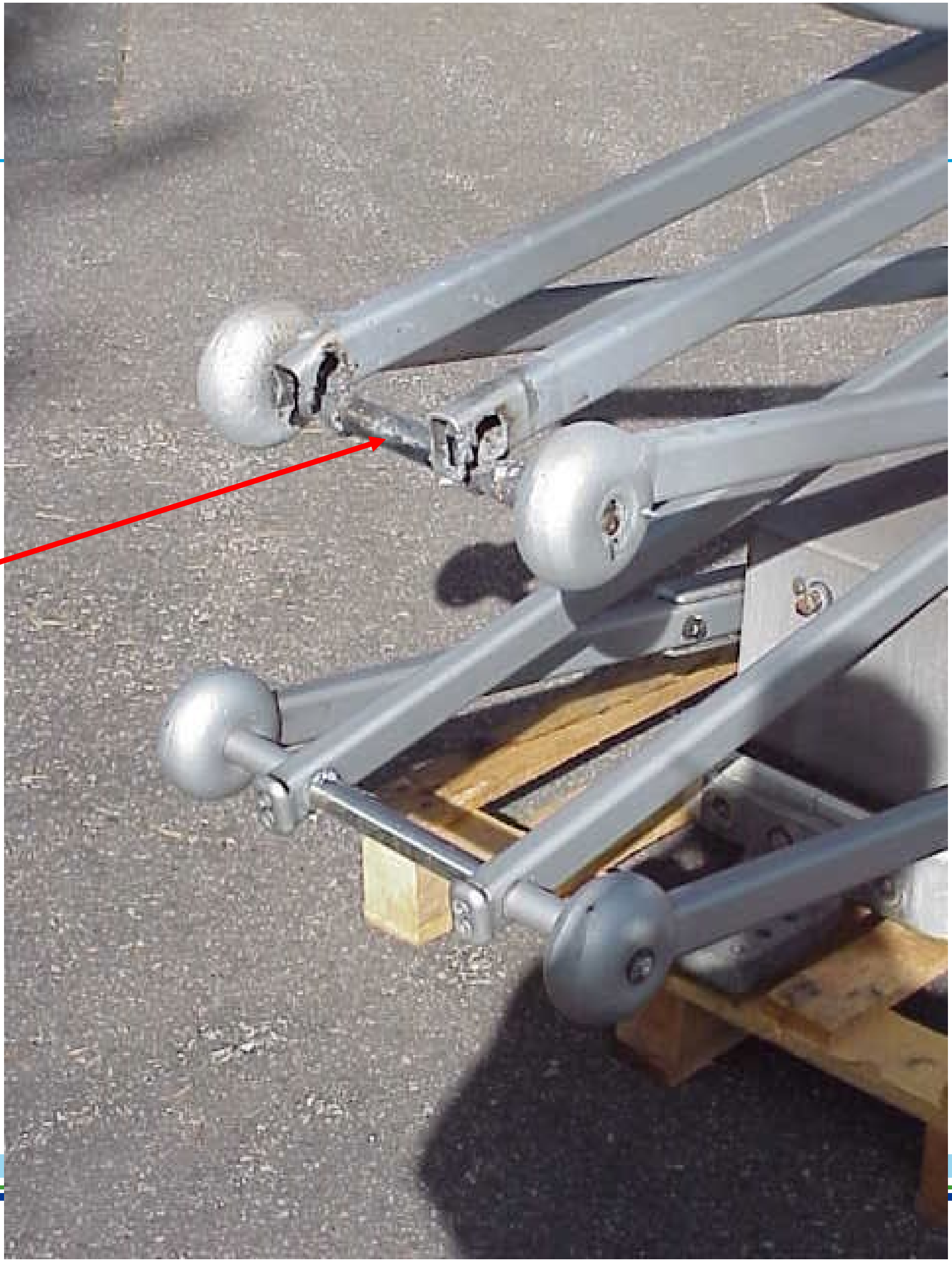
2003-09-23 Swedish Blackout – 5000 MW lost




A
A
Overheating
C
A
Wind

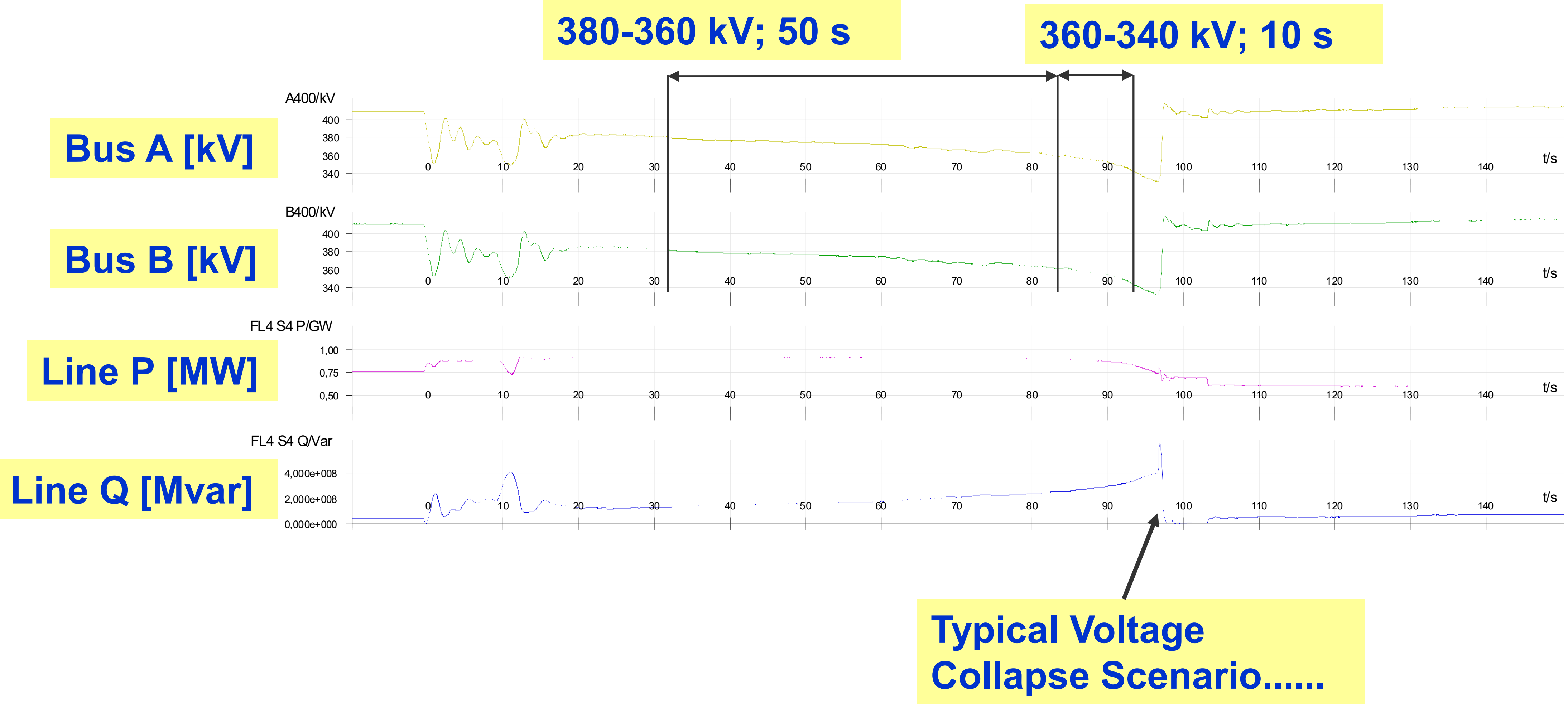
Damaged Disconnector

Overheating



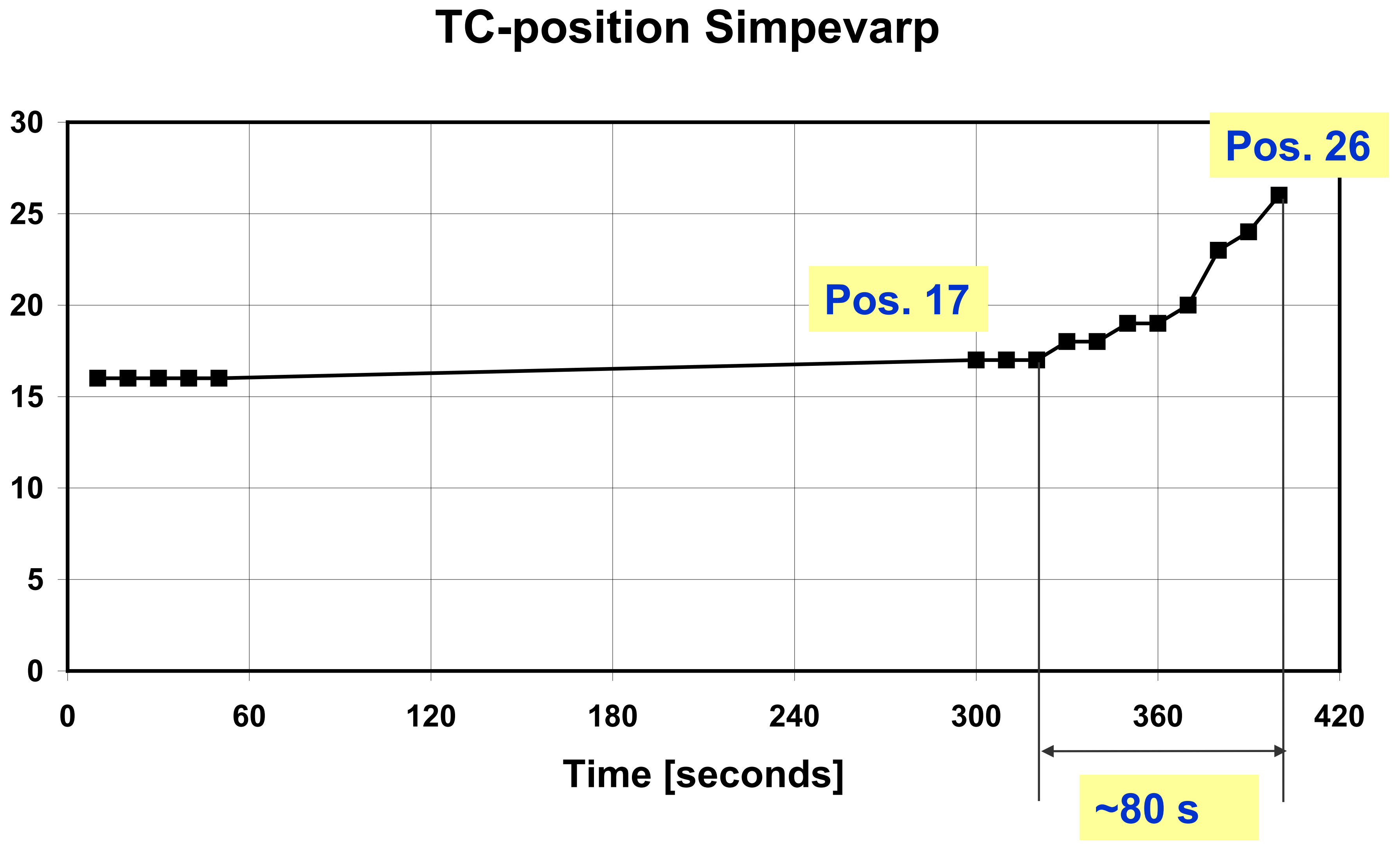
Damaged Disconnector

Recordings from Mid Sweden

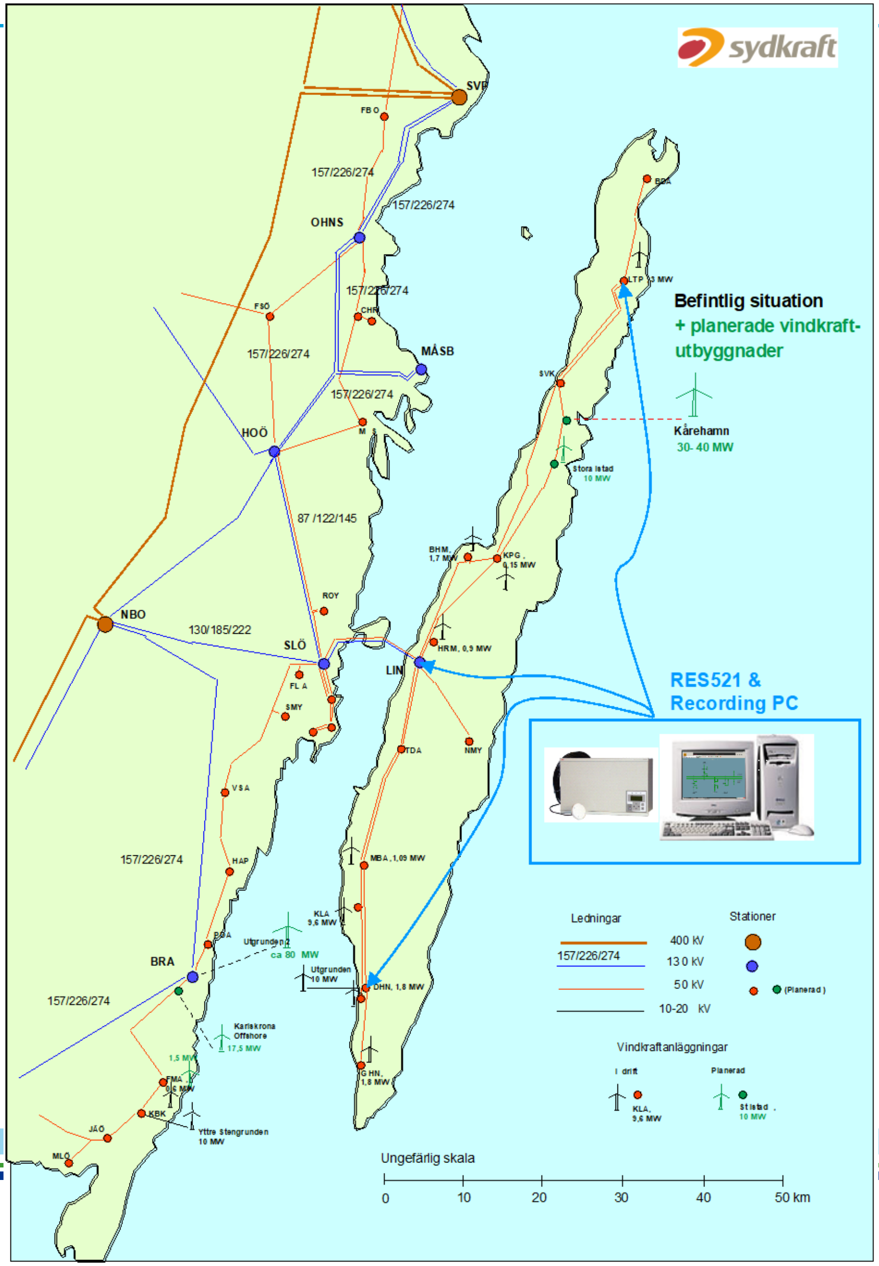


Plenty of time to take remedial actions, triggered by the low voltage .....

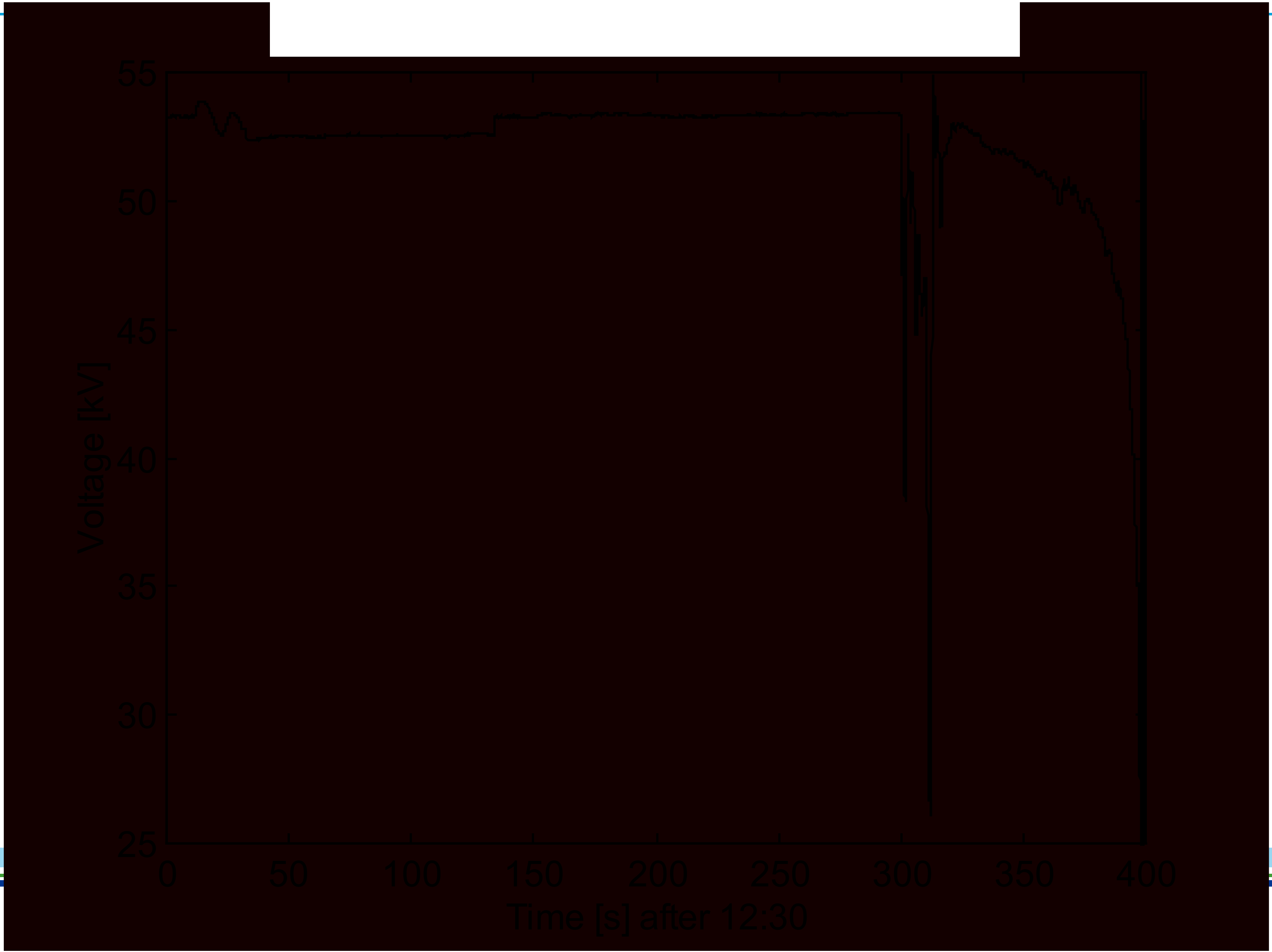
Tap Changer 400/130 kV South East Sweden



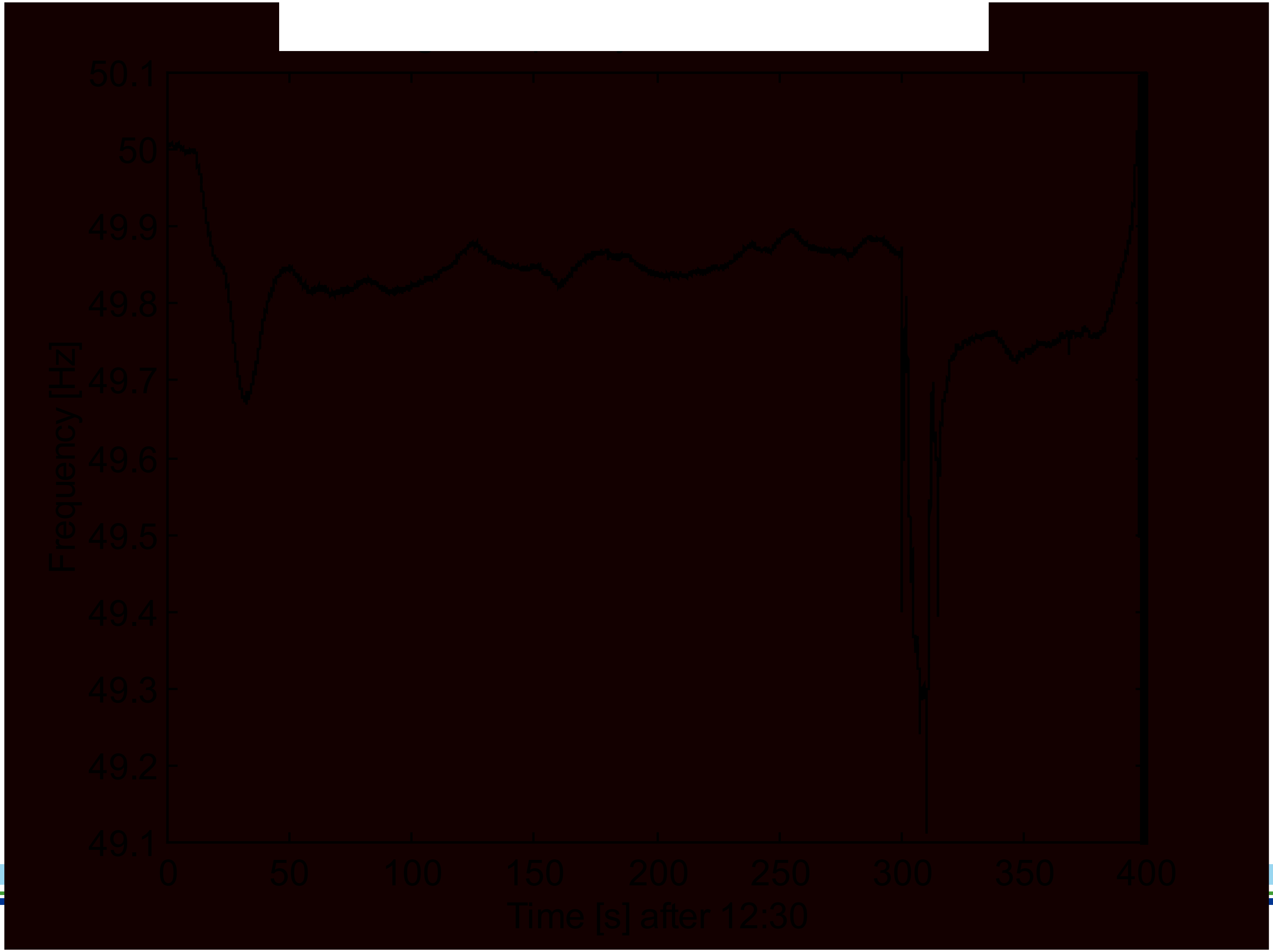
EU project recordings on Öland summer 2003



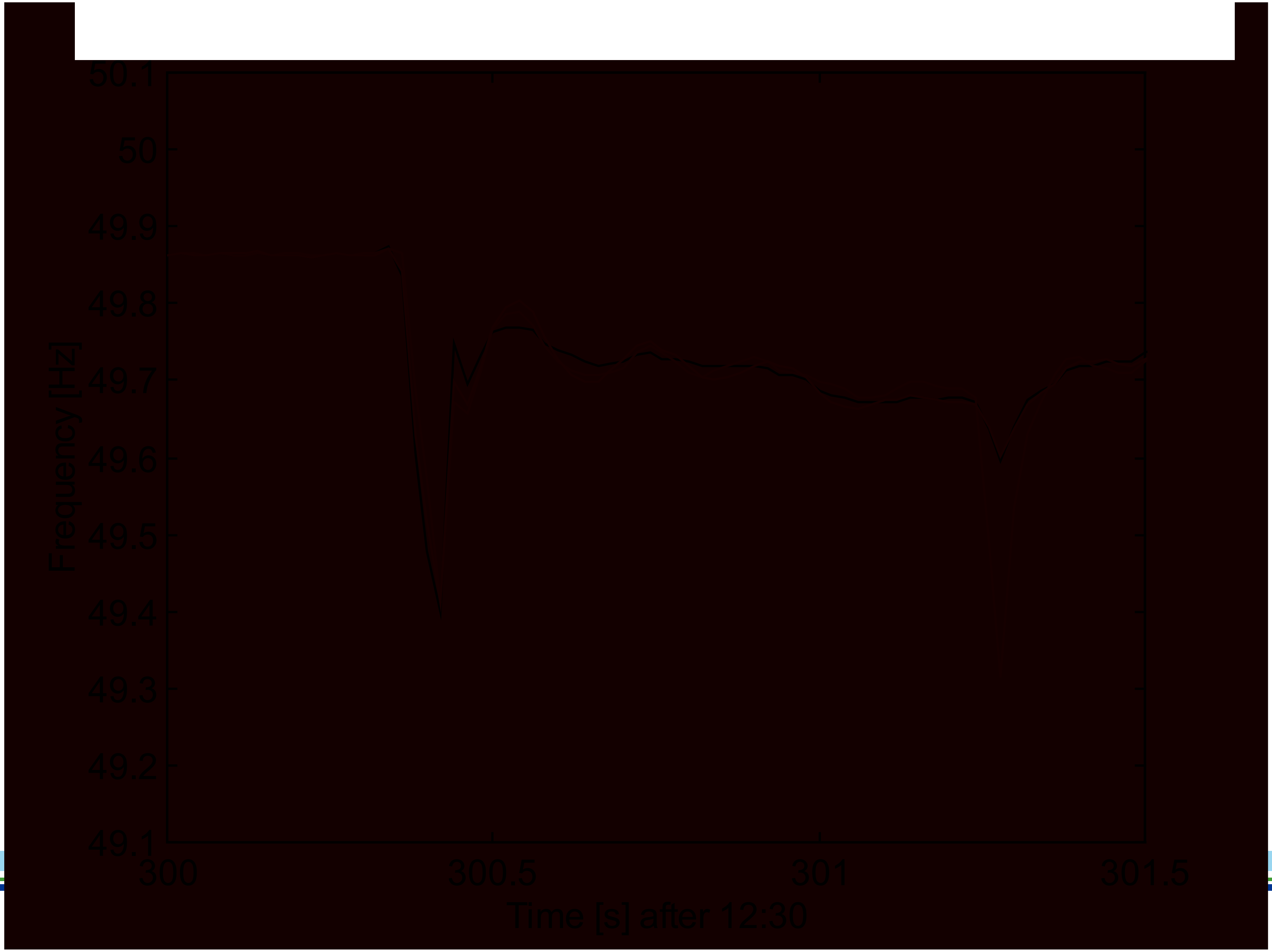
Voltage Magnitude 50 kV, 2003-09-23



Frequency on a 50 kV bus



Frequency from 3 different buses – 50 kV



Concluding Remarks

- There is a lot to learn from the history
- Proper – time stamped - recordings is of utmost importance for reliable disturbance investigations
- Disconnectors are critical sources of fault – Disconnectors are being removed
- ABC-switchgears are redesigned to double-bus double-breaker design
- Maximum mesh of the system can be questioned
- We are facing a transition towards more and more inverter connected weather dependant generation, which adds new types of "disturbances", e.g. due to unexpected shift in weather conditions
- There is a great potential for protection systems for the southern part of Sweden based on PMUs and communication.

DNV

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