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- experience with the operation of HVDC interconnections

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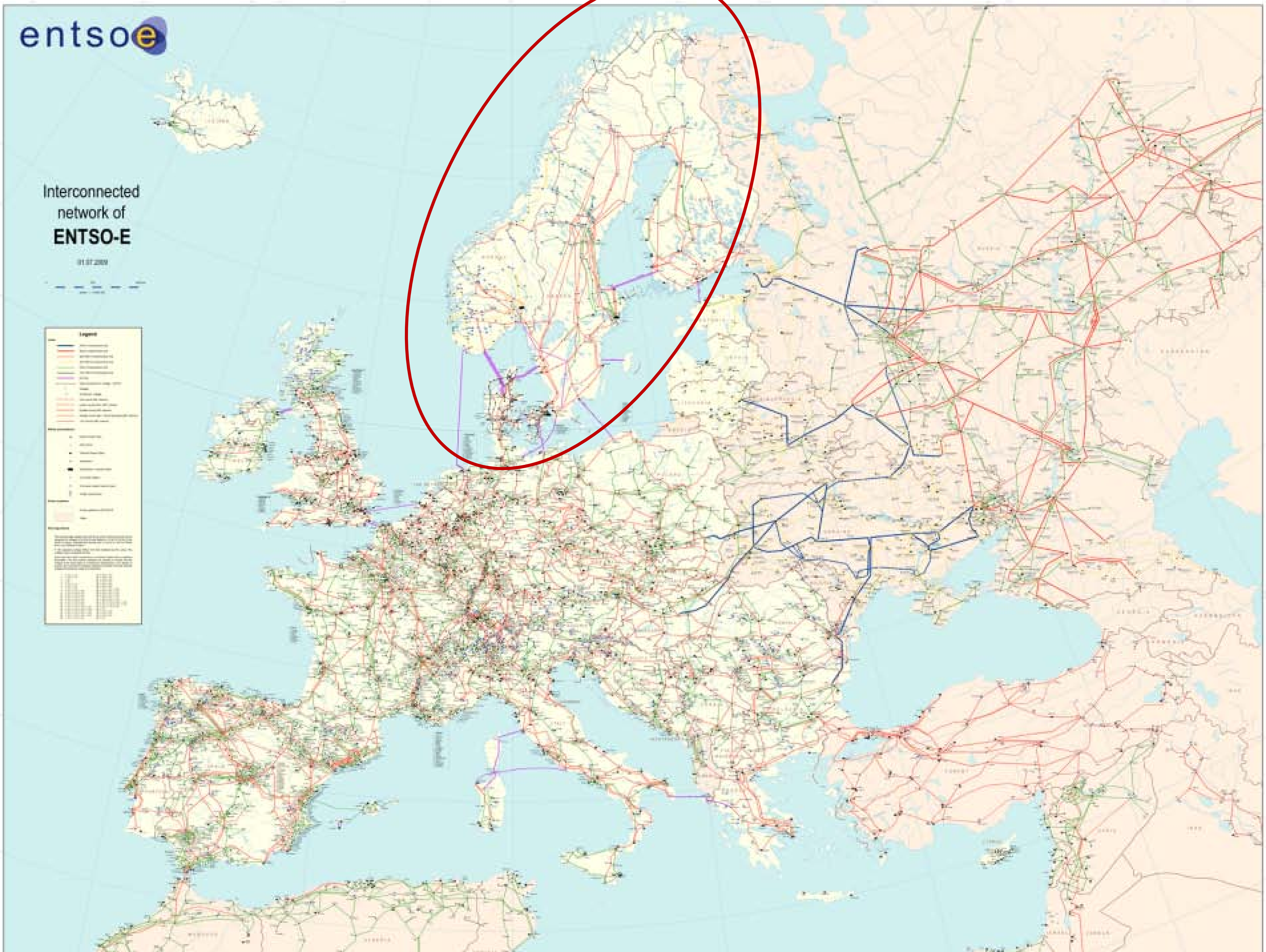
entsoe
Interconnected
network of
ENTSO-E
Legend

The Nordic synchronous area

- Consists of Norway, Sweden, Finland and Zealand (eastern part of Denmark)
- Total peak load is approx 70.000 MW, and minimum load is approx 25.000 MW
- High amount of flexible hydro production
- 9 HVDC links (with 13 cables) connecting the Nordic synchronous area with other areas
  - 2 links from Norway, 2 from Zealand, 3 from Sweden and 2 from Finland
  - Total capacity is about 6.800 MW (and increasing)
- The HVDC-cables are important for the security of supply in Nordic system
  - Import in dry periods and export in wet periods
  - In periods with normal hydrological balance the flexible hydro power leads to export to Continental Europe during the day and import during night and week-ends

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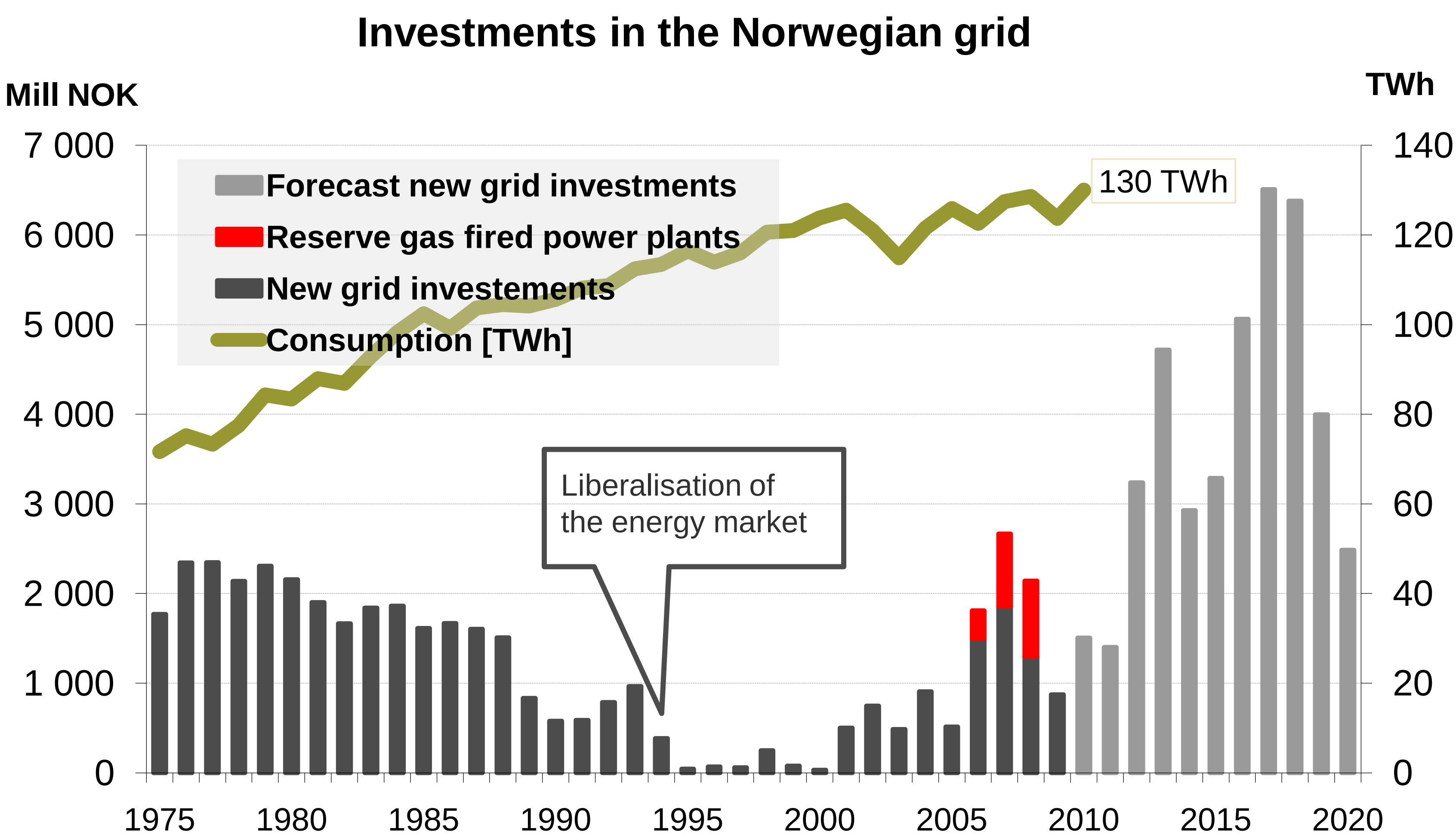
- Transmission system operator and grid owner
- Responsible for secure delivering of electricity – at all time
- Own and operate
  - One national control centre and three regional control centres
  - App. 10 000 km electricity grid
  - 140 substations
  - Four interconnectors to the continent
  - 900 employees
- Are building the next generation electricity grid

Grid development - past, present and future



(*): New grid investments only, excl. reinvestments, IT/Tele, and construction interest. Forecast dated summer 2010

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The Statnett HVDC Interconnectors

Skagerrak 1 og 2
- Between Norway and Denmark, in operation since 1976 and 1977
- 2 x 270 MW, originally bipole, changed in 1993

Skagerrak 3
- Between Norway and Denmark, in operation since 1993
- 500 MW, operates as bipole together with SK1+2

NorNed
- Between Norway and the Netherlands, in operation since 2008
- the world's longest HVDC cable link
- 700 MW, bipole

Under construction; Skagerrak 4
- Between Norway and Denmark, planned operation 2014
- 700 MW, will operate as bipole together with SK3,
  SK1 and 2 to be bipole again

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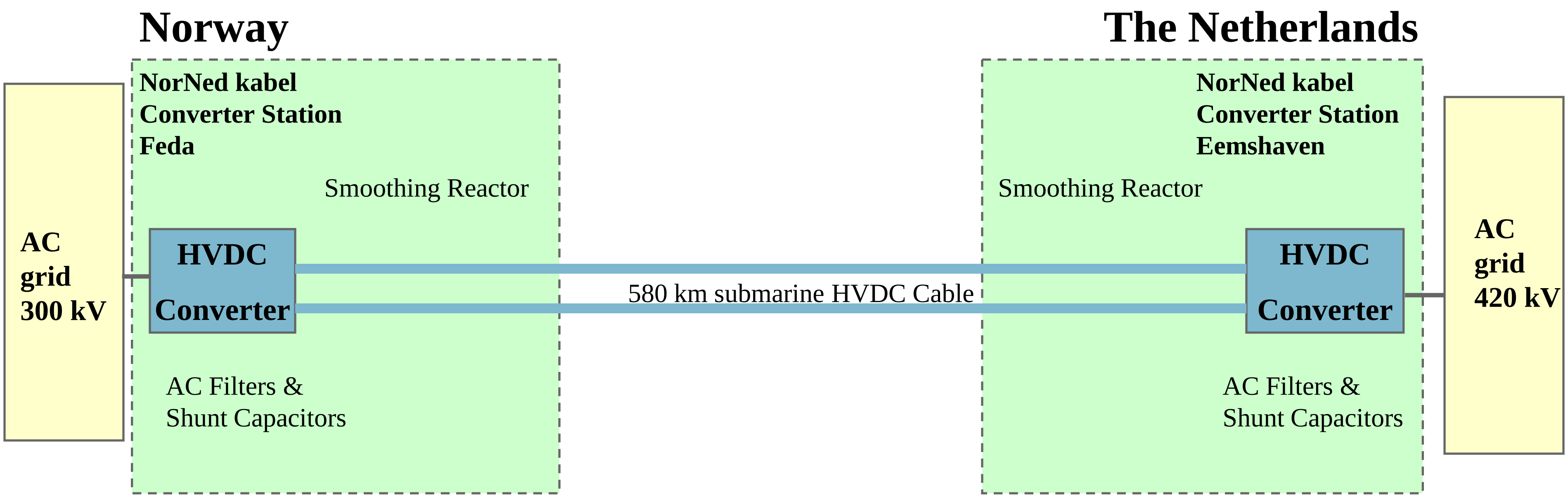
NorNed kabel HVDC Transmission system

Main data: 700 MW receiving end, +/- 450 kV DC



- The Converters make the connection of the DC link to the AC systems possible.
- Each converter can operate as rectifier (AC to DC) or as inverter (DC to AC)
- Transmission loss < 5%

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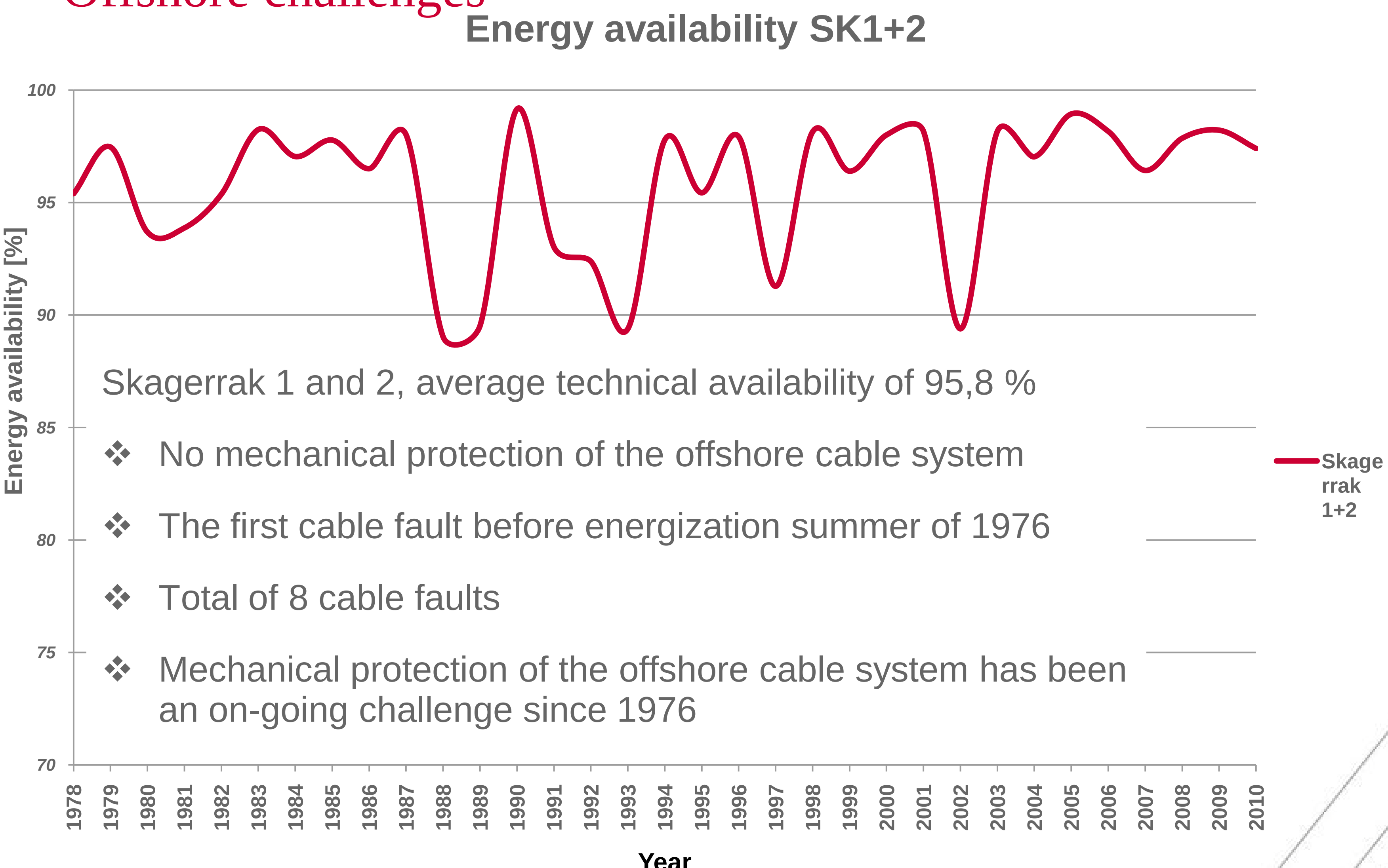
Experience with the HVDC interconnectors

- Technically complex systems and installations onshore and offshore
- Complex and time consuming operations in normal and in emergency situations during the life time of the link
- Requires highly compentent personell in all phases of the life time of the link
- Important decisions for technical availiability are made at an early stage in the project phase;
  - regarding level of redundancy
  - reserve components (ex. transformers, smoothing reactors)
  - cable route and level of mechanical protection
- Design and characteristica for each link is taken into account for planning operation, maintenance and emergency preparedness in the operational phase
- Experience from operation of the existing links are important input to building the next HVDC links

Offshore challenges



Skagerrak 1 and 2, average technical availability of 95,8 %

- No mechanical protection of the offshore cable system
- The first cable fault before energization summer of 1976
- Total of 8 cable faults
- Mechanical protection of the offshore cable system has been an on-going challenge since 1976

Energy availability according to the international standard "Cigre's protocol for reporting the operational performance of HVDC transmission systems 14-97 (WG 04)".

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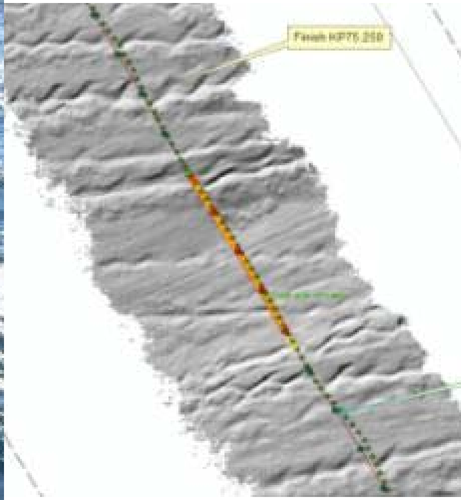
Offshore survey, maintenance and mechanical protection reduce number of cable faults.

Still need for emergency preparedness!



Risk&vulnerability analysis

Reliability centered maintenance, LongTermplan

Emergency preparedness plans

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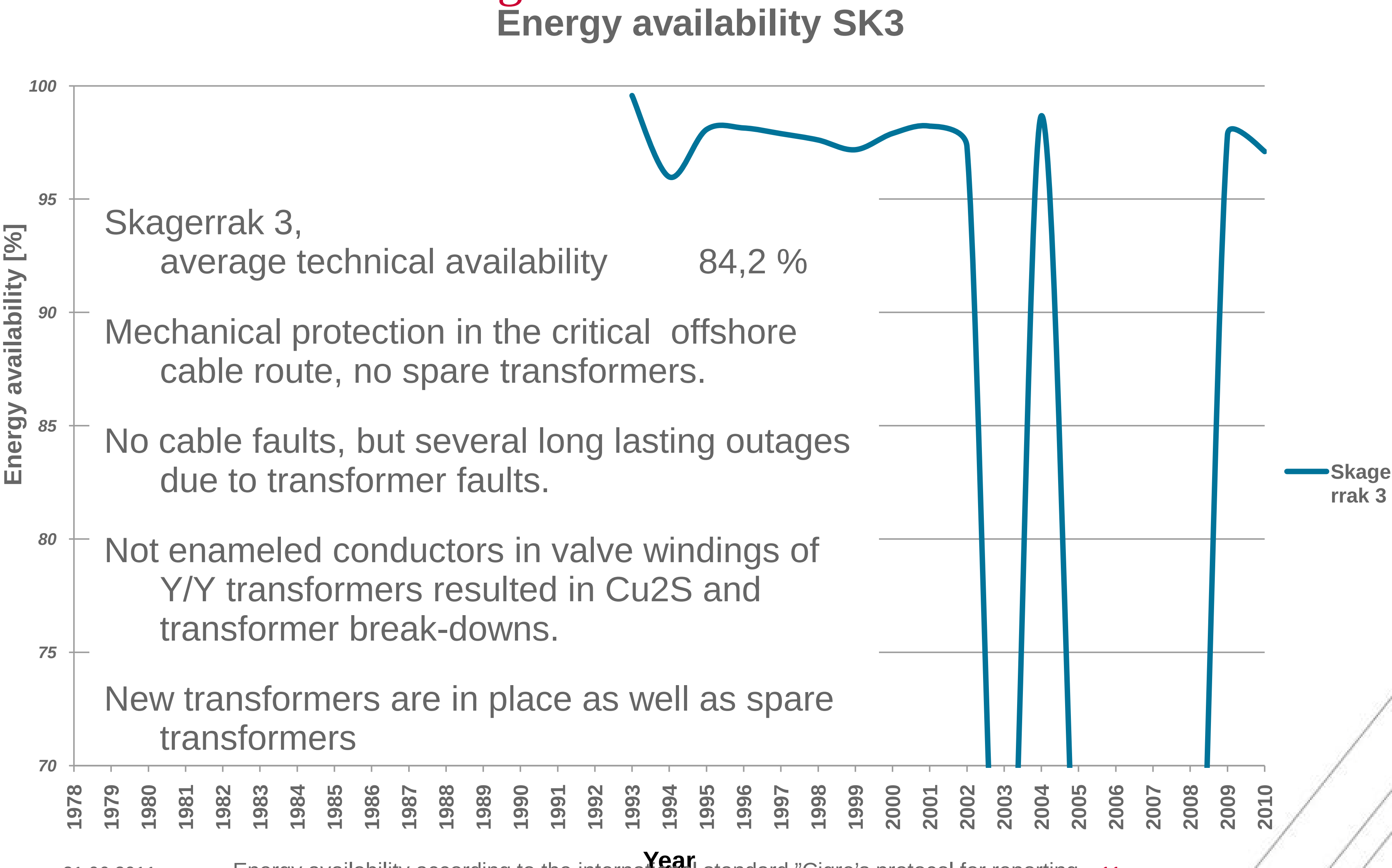
Transformer challenges



- Skagerrak 3,
  - average technical availability 84,2 %
- Mechanical protection in the critical offshore cable route, no spare transformers.
- No cable faults, but several long lasting outages due to transformer faults.
- Not enameled conductors in valve windings of Y/Y transformers resulted in Cu2S and transformer break-downs.
- New transformers are in place as well as spare transformers

Energy availability according to the international standard ”Cigre’s protocol for reporting the operational performance of HVDC transmission systems 14-97 (WG 04)”.

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Onshore transformer problems

New spare transformers

Year of commision 1993

1. July 9 2003; failure due to Coppersulphide,
   Repaired Dec 13 2003

2. May 27 2005; failure due to Coppersulphide,
   End of life Oct 1 2005

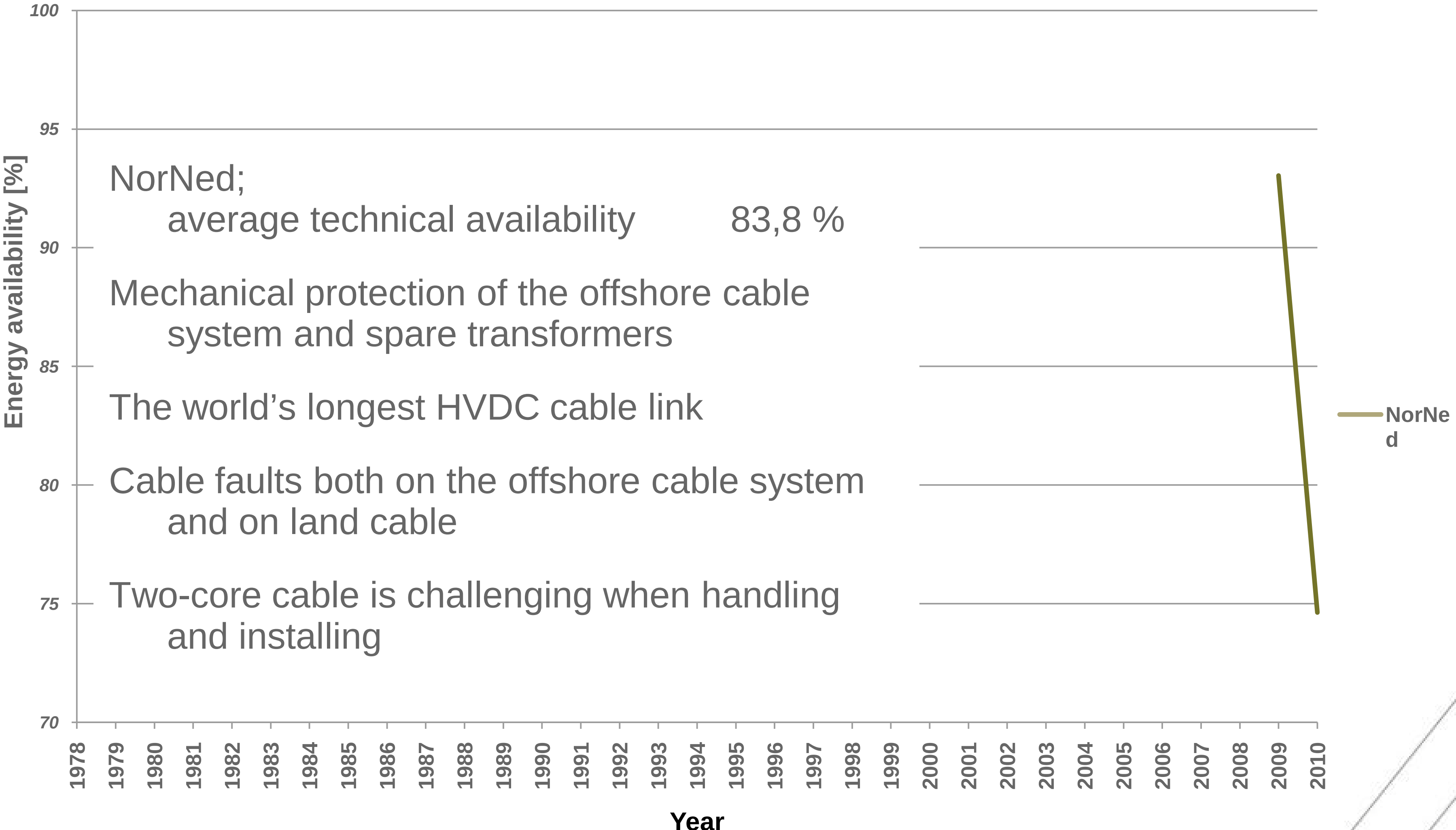
October 26 2005; New transformer installed

3. Jan. 23 2006; failure of OnLineTapChanger

Transformer faults are complex and serious, take a long time to repair – if possible.

Spare transformers are a good investment!

Energy availability NorNed



- NorNed;
  - average technical availability 83,8 %
- Mechanical protection of the offshore cable system and spare transformers
- The world's longest HVDC cable link
- Cable faults both on the offshore cable system and on land cable
- Two-core cable is challenging when handling and installing

Energy availability according to the international standard "Cigre's protocol for reporting the operational performance of HVDC transmission systems 14-97 (WG 04)".

35 years of experience with the HVDC interconnectors

- Good experience and extensive know-how
- Experience from operation of the existing links are important input to building the next HVDC links

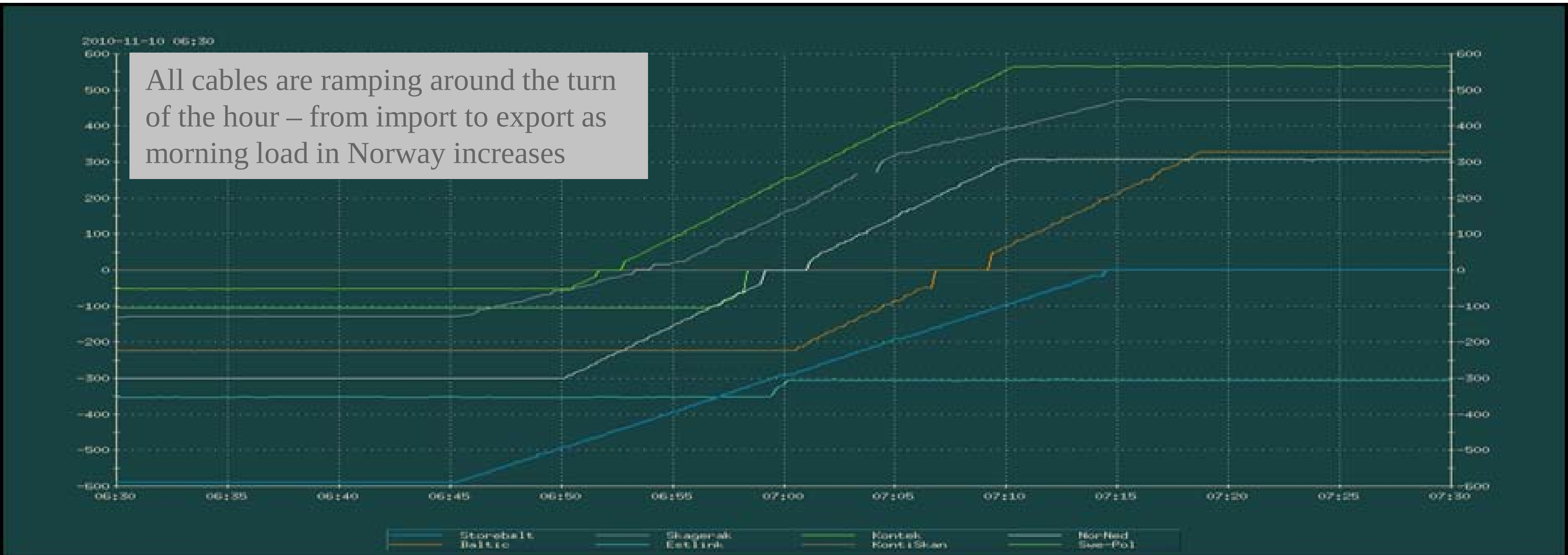
- Skagerrak 4 will be
  - VSC technology (HVDC Light), single core cables, mechanically protected cable system, high level of redundancy and spare transformers

- Systematic and attentive approach to operation, maintenance and emergency preparedness in the operational phase
  - Risk and vulnerability studies, long term planning of preventive maintenance og good emergency preparedness systems in case failure

Challenges in the system operation - ramping

- Ramping is defined as the planned change in power exchange on the HVDC-links from one hour to the next
  - Maximum ramping is 600 MW/hour and 30 MW/min on each HVDC-link
  - For the Nordic synchronious area: 5400 MW/hour and 270 MW/min.

- Ramping restrictions are necessary to handle both the balancing of the system (frequency) and congestions in the grid



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Challenges in the system operation

- ❖ Frequency deviations – introducing secondary reserves, nordic plan for handling this in the Nordic area
- ❖ Voltage control – new investments in Norway
- ❖ Short cuircuit power ratio in import situation is low
  - – plan for installing rotating VAr compensator
  - – choosing new technology (VSC) for next HVDC link
- ❖ Costs related to system services increase

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Conclusions

- Good experience with the operation of the interconnectors
  - As HVDC links and as part of the power system
  - Challenges have been met and handled
  - Requires highly compentent personell in all phases of a project and during the operational phase
  - Requires a strong grid, tools for voltage control and balancing tools
- 35 years of experience
  - Systematic and attentive approach to operation, maintenance and emergency preparedness – risk and vulnerability analysis, reliability centered maintanance and emergency preparedness plans
  - Experience from operation of existing links are included in the design of new links
  - Close follow-up of system behaviour and designing new solutions
- Some new challenges for Norway and for the Nordic area – plans are in place