NEW 400 kV UNDERGROUND CABLE SYSTEM PROJECT IN JUTLAND (DENMARK)

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Abstract: This paper gives the history of the 400 kV Aarhus - Aalborg project in Denmark, describes the Environmental Impact Assessment process, from the public hearings to the political decision of undergrounding parts of the total route of the line.

After a short description of the three siphons (environment, cable route, etc) and the reasons why undergrounding has been decided, the technical issues regarding the integration of the three cable systems in siphons are addressed: cable dimensioning (thermal rating), overload capabilities, selected laying methods and techniques. The case of the crossing of the Mariager fjord is detailed

Keywords:EHV Cables, siphons

Résumé: Ce rapport retrace l'historique du projet 400 kV du Jutland, décrit la démarche d' Evaluation de l' Impact sur l' Environnement depuis les débats publics jusqu'à la décision de mise en souterrain de quelques sections de la ligne.

Après une courte description des trois siphons (environnement, tracé) et un rappel des raisons ayant amené à la décision de mise en souterrain, les aspects techniques liés à l'intégration des trois siphons sont abordés: dimensionnement du câble, capacités de surcharge, techniques de pose. Le cas particulier de la traversée du Fjord Mariager est abordé en détail.

Mots clés: Câbles THT, siphons

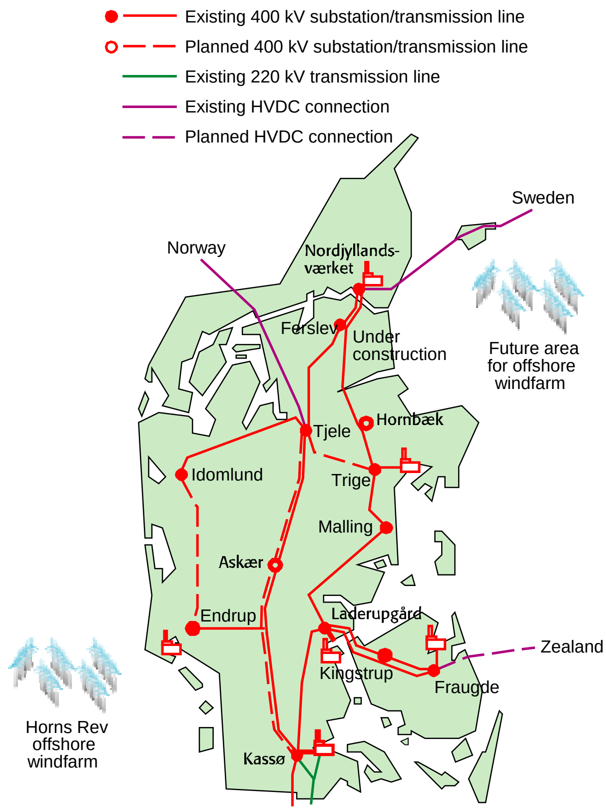
1. Introduction

The building of a 400 kV connection between Aarhus (Trige substation) and Aalborg (Nordjyllandsvaerket substation) will complete a ring structure of the main Jutland high-voltage transmission grid.
Planning and government evaluation of the 140 km transmission line have been going on for more than ten years. The Danish Energy Council approved the project in early March 2001. It is now intended that the high-voltage transmission line will enter operation in 2004. The line will be build and owned by the western Danish transmission system operator Eltra.
The overall project for the establishment of this 400 kV high-voltage connection between Aarhus and Aalborg includes three sections with underground cables. The three 400 kV cable sections (siphons) will run across the Mariager Fjord, the Gudenaa Valley, and through the Indkilde Valley, with an overall route length of 14 km.

Considered together, the three siphons are one of the world's largest cable projects. It is also the first time that 400 kV cables will be buried under agricultural land and nature reserves. For all three cable sections in connection with the Aarhus-Aalborg project, two 400 kV cable systems will be laid in parallel.

2. Project Description

2.1 Purpose of the Aarhus-Aalborg transmission line



The 400 kV grid is the backbone of the electricity system in Denmark.

The building of a 400 kV connection between Aarhus (substation in Trige) and Aalborg (substation at the Nordjyllandsvaerket) will complete a ring structure of the 400 kV network on the peninsula of Jutland.
Planning and government evaluation of the line have been going on for more than ten years. The Danish Energy Council approved the project in early March 2001. It is now expected that the high-tension transmission line will enter operation in the autumn 2004.

Three cable routes

It will cost approximately 140 million Euro to build the transmission line. The amount includes the cost of the 400/150 kV overhead line, the three 400 kV cable sections and a complete restructuring of the 150 kV network in the city of Aalborg.

The Danish Energy Council's approval of the construction was based on the following: it evaluated that a 400 kV connection will be necessary in order to safeguard service security, transport needs in connection with system imbalances between power-plants and windmills, and the recently legislated opening-up of the electricity market.

Sturdy and stable

The 400 kV transmission grid will be the backbone of the electricity system in the Jutland/Funen area in the future and it is able to transport large amounts of energy without significant loss. But the effective operation of the 400 kV network requires a grid structure that is both sturdy and stable. This is why the Danish Energy and Environmental policy is focused on a 400 kV ring structure as the basis for handling the very large, and increasingly decentralised, energy production from small combined cycle power stations and wind turbines.

The extreme variations in local electricity production makes it necessary to transport large amounts of energy alternately to and from the individual geographical areas. The main transmission grid will ensure stable voltage in the local distribution systems.

Bottlenecks are expensive

When the grid lacks capacity, so-called "bottlenecks" occur. Moreover, lack of capacity in the main grid leads to increased transmission loss, which is also economically detrimental to consumers.
The grid must therefore be solid and reliable. It must be built in a ring so that, when maintenance is carried out or when there is an interruption/breakdown on a line, voltage is automatically assured from the opposite side at the substations on the ring. The grid must have the same strength and sturdiness throughout.

The new line between Aalborg and Aarhus has to complete the Jutland ring-connection. It is therefore important that it is just as strong, effective and flexible as the rest of the grid.

2.2 Project History

The detailed planning of the 400 kV transmission line began in 1989. During twelve years intensive negotiations with local, regional and authorities were carried out. The process included numerous public hearings and meetings. During the discussions a dozen of different route alternatives were evaluated into details. A number of very active local protest groups and politicians took part in the discussions and some of them succeed to influence or change the project significantly.

As a part of the project planning an Environmental Impact Assesment study (EIA study) was carried out. This study was used to asses the consequences of different route alternatives of the overhead line and for example the use of cables instead of overhead line at some specific route sections. The study also outlined the environmental consequences during construction, operation and end-of-life for the transmission line

The EIA-report was used as the background material for the public project hearings. Two types of hearings were carried out. The initial hearings had the purpose of collecting route alternatives as well as technical alternatives from the public. The final hearings was carried out after the EIA-report was finalized and these hearings was used by the political decision makers to set up the conditions for the final permission of the line.

When the planning of the line started in 1989 it was supposed to be an overhead transmission line project only. However the final permission given in March 2001 had the precondition that three sections of the line shall be undergrounded and that underground cables shall be used to replace a number of 150 kV-lines in urban areas of the same region.

The reasons for the decision to use underground cables on three sections of the 400 kV line are environmental (to reduce the visual impact), closeness to urban areas (to increase the value of land near the line) and political (due to influence from politicians elected in the area and strong protest groups).

2.3 Cable sections

As already indicated, the three 400 kV cable sections will run across Mariager Fjord and the Gudenaa Valley, as well as through the Indkilde Valley, with an overall route length of 14 km.

- **Tebbestrup-Hornbaek cable section**

The crossing through the Gudenaa River Valley west of Randers will be done by cable laying on a 4,5-km long section between the transition compounds named Tebbestrup and Hornbaek. At the same time, the existing 150 kV and 60 kV connections, which currently cross the River Valley as overhead cables, will also be undergrounded.

Two 400 kV systems, one 150 kV system and two 60-kV cable systems will be buried in trenches up to 1.5 m deep in a 24 m wide Right Of Way (ROW). Since each cable system includes three cables, there will be a total of 15 high-tension cables across the River Valley.

Each cable system will be laid in strong plastic pipes under the railway, under the roads and under the Gudenaa River. The plastic pipes will be installed in small tunnels up to nearly 70 cm in diameter made by directional drilling.

Each tunnel will contain a single cable system.

In order to ensure the dispersion of heat from the cables, the plastic pipes in the tunnels will be filled with bentonit.

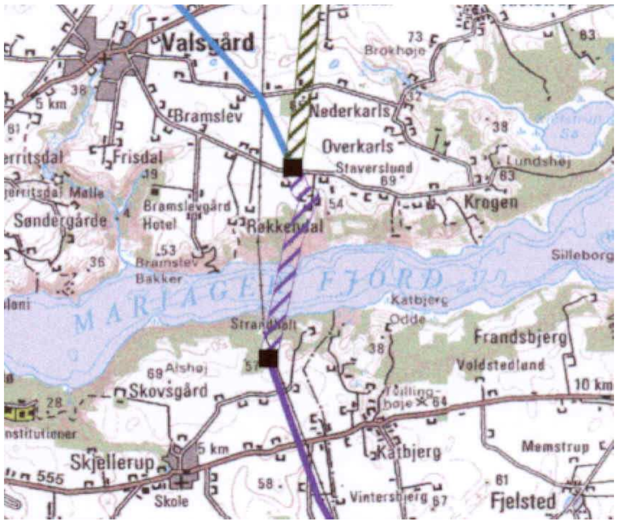
- **Katbjerg-Bramslev cable section**

The new 400 kV cable connection will cross the Mariager Fjord, on a 2.5 km long section between the transition compounds named Katbjerg and Bramslev, east of the town Hobro. At the same time, the existing 150 kV connection, which currently crosses the fjord on high, overhead-cable pylons, will be dismantled.

This section will include two 400 kV cable systems and one 150 kV cable system, which will be buried on the slopes on both sides of the fjord in trenches 1.5 m deep. The cables will be pulled over the fjord through strong, water-filled plastic pipes, previously laid on the bottom of the fjord from a ship. Each of the nine high voltage cables will be pulled through its own pipe.

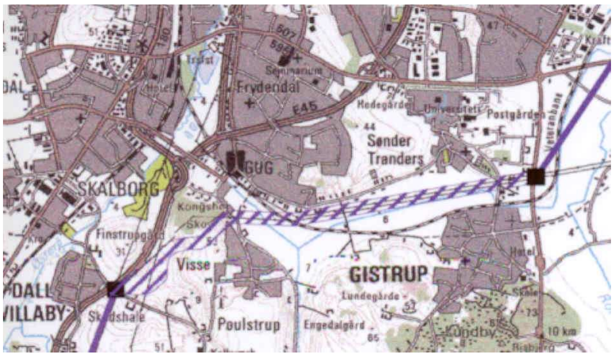
Cable and pipe for the Mariager Fjord crossing

Close to land, the pipes will be buried in the seabed of the fjord but, for most of the 700 meter long crossing, they will be laid directly on the seabed (for environmental reasons). The cable burying will stir up organic silt from the bottom of Mariager Fjord.



- **Cable section through the Indkilde Valley**

In the Indkilde Valley, south of Aalborg, the new 400 kV connection will be laid as underground cables on a 7.0 km long section between the transition compounds named Skudshale and Gistrup. An existing 150 kV overhead line along a part of the same route will be buried at the same time.



As for the cables in the Gudenaa River Valley each cable system will be laid in strong plastic pipes under major roads and under the railway. The plastic pipes will be installed by directional drilling and filled by bentonit after the cables have been pulled.

2.4 Cable system dimensioning

The cable sections have been designed according to the principle of equivalent short time load of the cables and the overhead line.

The overhead line has a nominal rating equal to app. 2000 MVA (2800 A) and the short time load capacity is for safety reasons (sagging limits of conductors) limited to only a few minutes.

The two cable circuits in parallel have a nominal continuous rating of only 1000 MVA (1400 A). However, if the short time load capacity of the cables is taken into account the 400 kV cables can be loaded at 2000 MVA (2800 A) for nearly 30 hours provided that the cables have been preloaded at a load of 500 MVA (700 A) or less. At the end of the 30 hours time period the conductor temperature is still less than 90 Degrees C. Thus the 400 kV cables will not be operated at overload.

Maximum load during normal operation is expected to be app. 800 MVA (1100 A) and at a typical preload of 500 MVA (700 A) or less each cable circuit can be loaded at 800 MVA (1100 A) for more than 100 hours. This time should be sufficient to do a repair on one phase of a cable circuit and therefore, an outtage of one 400 kV circuit is not expected to have any consequences for the operation of the transmission line.

- **Technical specifications**:

The 400 kV cables for the project have been designed according to the following specification:

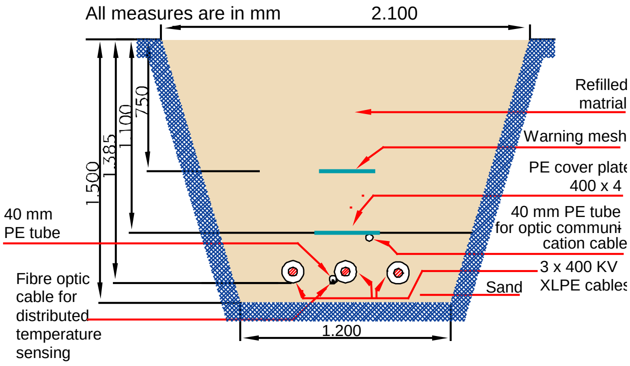
- *Design requirements*
  - -life time: 40 years
  - -standards: according to IEC 62 067[1]
  - -cable design: XLPE, laminated covering for land cables
- *Design parameters:*
  - -system voltage U : 230/400(420)kV
  - -frequency: 50 Hz
  - -Nominal continuous current (at Load Factor LF= 1) : 700 Amps
  - -Short-circuit current: 40,0 kA for 1 sec.
- *Installation conditions:*
  - -Cable lengths pr. drum: below 900 m
  - -Number of joint-pits: 5 (on the Tebbeestrup-Hoernbaek section) + 3 (on the Katbjerg-Bramslev section) + 8 (on the Skudshale - Gistrup section)
  - -Distance between 400 kV circuits: 6 m
  - -Laying depth: 1.2 m (to the top of the cables)
  - -Thermal resistivity of backfill material (sorted sand): 1.0°C.m/W
  - --Thermal resistivity of surrounding soil: 1.0°C.m/W
  - -Maximum ground temperature: 15 °C
- *Screen bonding arrangement*: cable screens shall be cross-bonded and/or single point grounded
- *Load specification*: external temperature on the cable surface when directly buried at full load (LF=1): <50°C

- **Cable construction**

The cable conductor shall be made of stranded aluminum or copper. The cable insulation shall be dry extruded XLPE. The cable shall be longitudinally and radially watertight. Radial watertightness of land cable shall be obtained by a folded aluminum foil. The cable oversheath shall be made of High Density PolyEthylene and the cable shall have a black extruded conductive layer on the outer sheath.

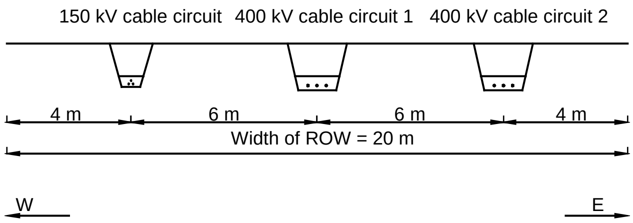
- **Laying techniques**

The cables installed on land will either be directly buried in the ground or pulled in ducts installed by directional drilling.



Typical laying configuration for the land cable

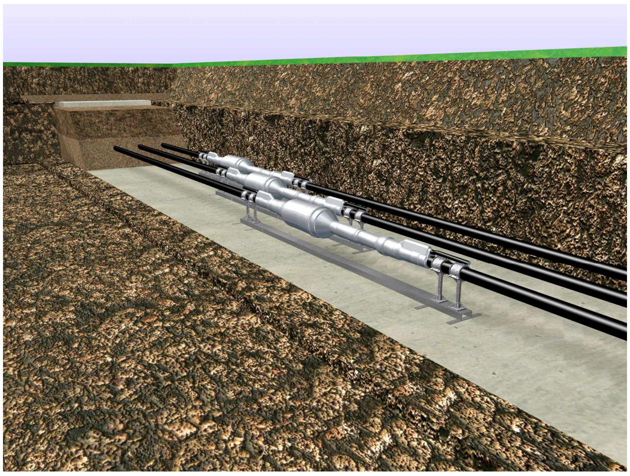
For most of the cable length, the cables will be directly buried and laid in sand. The cables will be protected by plastic cover plates and warning mesh. In the same cable trench two fiber optic cables will be pulled in smaller 40 mm ducts. The one fiber cable is for communication purposes and the other fiber optic cable is to be installed close to the centre phase and will be used for distributed temperature sensing/temperature monitoring of the cable.



The distance between the two 400 kV cable circuits and the distance to neighbouring 150 kV cables has been set to 6,0 meter.

2.5 Joint pits

There is no joint chamber. All joints are installed on a concrete raft and directly buried

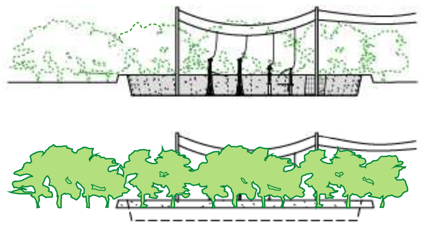


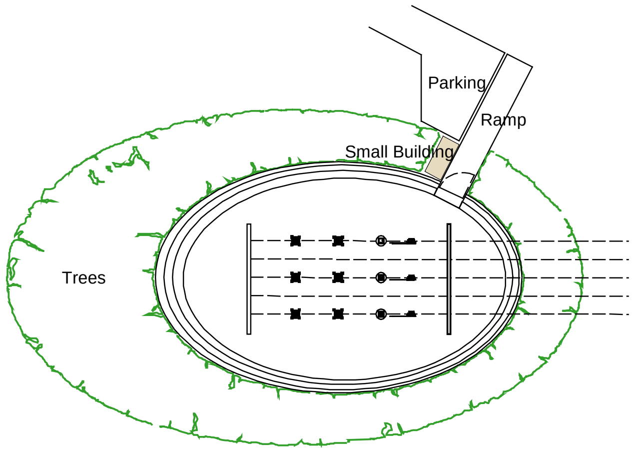
Directly buried joints

2.6 Transition compound design

Two different designs of transition compounds will be used on the line. For the transition compound in Tebbestrup, Hornbaek, Katbjerg, Skudshale and Gistrup a conventional design based on lattice steel towers/supports will be used. For the transition compound in Bramslev the layout will be visually adapted to the "design towers" used on a 25 km section of the overhead line. On this section of the line the design of the towers has been determined by an open design competition.

Both types of transition compounds contains terminations, surge arresters, grounding connectors and a dead-end tension tower for the overhead line.





Transition compound

3. Description of the adopted equipment

3.1 Cable

The specified ampacity is achieved with a 1200 mm² aluminium conductor. The insulation thickness of the cable (28 mm) has been chosen starting from the experience obtained in several long-term tests on complete cable systems including significant length of cable, joints and terminations carried out according to various CIGRE recommendations [2][3], Resulting operating stresses are 12.5 kV/mm on the conductor screen and 6 kV/mm over insulation screen [4]

Short circuit current carrying capability is obtained by a spinning of 117 aluminium screen wires with a diameter of 1.8 mm.

Longitudinal water blocking is achieved by swelling tapes in the conductor and below and above the screen wires

For the land cable, the radial water barrier is made by a 0.5 mm aluminium laminated foil oversheathed with a 5mm HDPE extruded layer.

For the Mariager Fjord crossing, the cable core is exactly the same and to improve the corrosion performance of the cable (the cables will be immersed into salt water) and increase the weight, the laminated aluminium foil is replaced by a lead sheath oversheathed with a 5 mm HDPE jacket. In order to limit the number of cables laid on the seabed at the fjord crossing, optical fibres in stainless steel tubes are inserted in the stranded screen wires of the cable. The joints on each side of the Mariager Fjord crossing are designed as transition joints between land cable and immersed cable.

Land cable construction

3.2 Accessories

- Joints are of the "One piece premoulded" type as described in Technical Brochures 89 [5] and 177 [6] issued by CIGRE WG 21.06. Five different types of joints have been designed, all using the same premoulded blocks, to cover all configurations
- Terminations are SF6 filled and housed in composite insulators to eliminate the risk of explosion

4. Type tests

Type tests on complete cable system as well as tests on individual components have been performed, including type tests on aluminium laminated screen: mechanical tests, corrosion tests and water-tightness tests . These tests were carried out according to CIGRE recommendations issued by CIGRE WG 21.14 in 1992 [7].

4.1 Electrical tests on the cable system:

As two different cable constructions were used for the Fjord crossing (lead sheathed cable) and for the land cables (laminated aluminium covering), the test loop for the electrical type tests was composed of:

- two outdoor terminations with composite insulators
- 12 m of land cable (with laminated aluminium covering)
- 12 m of lead sheathed cable
- one "one piece premoulded joint" with cross-bonding shield-break designed to make the transition between the two types of cables.

Electrical type tests

The test sequence was:

- Bending test
- Measurement of partial discharges at ambient temperature
- Measurement of Tan delta at 95 to 100 °C
- Heating cycle voltage test (20 cycles at 2 Uo)
- Switching impulse test
- Lightning impulse test
- Withstand test at power frequency
- Measurement of partial discharges

All results were complying with IEC requirements.
Once these tests were completed, several additional heating cycles at 580 kV were carried out to demonstrate the remaining safety margin.

4.2 Water penetration test (according to IEC 62067)

One 18 m sample of each cable construction was submitted to the bending test and 8m from each construction were tested to measure the water penetration in the conductor and under the water barrier.
After 24 hours at ambient temperature, the samples were subjected to 10 heating cycles and opened. No water penetration over 1.2m was observed (to be compared to the 4m on each side of the water injection specified in the IEC 62 067standard)

4.3 Tests on the laminated covering of the land cable

All following tests were made according to CIGRE WG 21.14 recommendations:

- -Impact test
- -Sidewall pressure test
- -Visual inspection after impact and sidewall pressure test
- -Corrosion test
- -Visual inspection after corrosion test
- -Adhesion strength of metallic foil after corrosion test

Impact and corrosion tests on laminated covering

5. After-laying tests

Cables and accessories are currently at the manufacturing stage. First drums of cable have been delivered and laying is expected to start in May, 2003. Commissioning is scheduled for 2004. According to Recommendations issued by CIGRE WG 21.09 [8] and in compliance with IEC 62 067 Standard, after-laying tests will consist of 1 hour withstand test at 1.7 Uo.

6. Conclusion

In order to get the permission to built the 400 kV transmission line between Aarhus and Aalborg the western Danish transmission system operator Eltra had to accept the use of underground cables on three shorter sections of the line.

The ampacity of the cables for the three sections have been chosen according to the transmission capacity required for the connection and if the short time load capacity of the underground cables are taken into account the ampacity of the cables matches the ampacity of the overhead line. The additional costs for using underground cables at the three section (including reactive compensation and parallel 150 kV cables) are estimated to be 20 million Euro and the cost ratio between cables and overhead line on agricultural land is calculated to be a factor of 4,5.

7. References

[1] IEC 62067, Ed. 1:"Power cables with extruded insulation and their accessories for rated voltages above 150 kV (Um=170 kV) up to 500 kV (Um=550 kV)-Tests methods and requirements", October 2001.

[2] CIGRE WG 21.03,"Recommendations for electrical tests, prequalification and development on extruded cables and accessories at voltages above 150 kV (Um=420 kV)", Electra No 151, December 1993.

[3] CIGRE TF 21.18," Recommendations for electrical tests, prequalification and development on extruded cables and accessories at voltages above 150 kV (Um=170 kV) and up to and including 500 kV (Um=550 kV)",Electra 193,December 2000.

[4] CIGRE WG 21.04, "Criteria for electrical stress design of HV cables", Electra No 169, December 1996.

[5] CIGRE WG 21.06 "Accessories for HV cables with extruded insulation" (CIGRE Technical Brochure No 89, 1995).

[6] CIGRE WG 21.06 "Accessories for HV cables with extruded insulation" (CIGRE Technical Brochure No 177, February 2001).

[7] CIGRE WG 21.14, "Guidelines for tests on high voltage cables with extruded insulation and laminated protective coverings", Electra No 141, April 1992.

[8] CIGRE WG 21.09, "After laying tests on High Voltage extruded cable systems", Electra No 173, August 1997.