1. Cable and System Data

1.1 400 kV Cable Data

The 400 kV land cables are constructed as follows:

Fact box with the following information:

1. Water-tight, compressed aluminium conductor with a cross-sectional area of 1200 mm^2. Diameter 42.9 mm.
2. Inner semi-conducting layer, 1.6 mm thick.
3. PE insulation, 28 mm thick.
4. Outer semi-conducting layer, 1.5 mm thick.
5. Semi-conducting tape.
6. Aluminium screen wires, 1.89 mm in diameter. Shield cross-section totals 328 mm^2.
7. Semi-conducting tape.
8. Metallic sheath/aluminium tape attached to the outer sheath, which is 0.5 mm thick. The cross-sectional area of this metallic sheath is 190 mm^2.
9. Smooth, high-density polyethylene outer sheath. Min. average thickness of the sheath is 5 mm. The outer part of the cable sheath is semi-conducting.

The external diameter of the entire cable is 125.5 mm
The cable weighs 14.3 kg per metre
Minimum bending radius is 1.9 m
The cable can withstand a maximum tensile force of 4,800 kg

400 kV land cable. Figure 5

The 400 kV submarine cables for the Mariager Fjord crossing are constructed as follows:

Fact box with the following information:

1. Water-tight, compressed aluminium conductor with a cross-sectional area of 1200 mm^2. Diameter 42.9 mm.
2. Inner semi-conducting layer, 1.6 mm thick.
3. PE insulation, 28 mm thick.
4. Outer semi-conducting layer, 1.5 mm thick.
5. Semi-conducting tape.
6. Aluminium screen wires, 1.89 mm in diameter. Shield cross-section totals 328 mm^2.
7. Stainless steel pipe with optic-fibres.

8. Semi-conducting tape.
9. Lead sheath. The sheath is 2.3 mm thick. The cross-sectional area of the lead sheath is 820 mm^2.
10. Smooth, high-density polythene outer sheath. Min. average thickness of the sheath is 5 mm. The outer part of the cable sheath is semi-conducting.

The external diameter of the cable is 128 mm
The cable weighs 23.8 kg per metre
Minimum bending radius is 1.9 m
The cable can withstand a maximum tensile force of 4,800 kg

400 kV submarine cable. Figure 6

1.2 Bonding

Cross-bonded Shield

On the Tebbestrup-Hornbæk and Skudshale-Gistrup sections the shields are cross-bonded. Each section is divided into one times three or two times three part sections.

Cable with joints. Focus on shield crossing and link boxes. Figure 24

In the joints where the shields are interrupted in order to be crossed, the shields are led out of the joint in one cable to be connected in a pre-fabricated joint. From here the two interrupted shields pass to a link box via a coaxial cable. In the coaxial cable, the innermost conductor is connected to the shield for one side of a given phase while the outer conductor is connected to the shield for the other side of the same phase.

Link box with surge arresters. Figure 26 (figure 28 may also be of help)

The link box holds surge arresters which are triggered if the voltage becomes too high. The surge arresters sit between the shield and earth.

The surge arresters can tolerate a d.c. voltage of 5 kV without triggering. In other words, it is possible to carry out a sheath test with 5 kV d.c. voltage on the cable shields without opening up the link boxes and removing the surge arresters.

The bottom part of the box is filled with plastic material which prevents water ingression through the bushings. The lid is screwed on suitably tightly. Then an elastic grouting compound is laid around the edge.

Single-point Bonded Shields

On the Katbjerg-Bramslev section the cables are single-point bonded. The shields are earthed in Katbjerg and in Bramslev, while the shields are open in joint no. 2 just north of the inlet.

Cable, link boxes and earthing cable. Figure 25

Together with the high-voltage cables, an insulated earthing cable (or equipotential cable) has been laid with a copper conductor cross-section of 300 mm^2. An earthing cable has been laid for each circuit. The earthing cable is connected to the earthing system in the two cable transition compounds Katbjerg and Bramslev, where the system of overhead lines is connected to the cable system. In the event of a high-voltage fault in the system of overhead lines, this cable will conduct the earth current.

Earthing cable. Figure 49
Link boxes with surge arresters. Figure 27

1.3 Laying Configuration

The cables are buried at a depth of approx. 1.2 m from the top of the cable to the surface. The cables lie in a flat configuration with a spacing of 300 mm.

Drawing of cable trench cross-section. Figures 16 and 20

The cables are laid in sand of varying grain sizes so the sand can be tightly packed. The maximum thermal resistivity of the sand and surrounding soil is estimated to be approximately 1 kelvin metre per watt. The distance between the centre lines of the two 400 kV circuits is 6 m.

Drawing showing circuit spacing. Figure 21

The excavated earth is used to refill the trench. The thermal conductivity around the cables therefore depends largely on the soil in which they are laid.

1.4 Distributed Temperature Monitoring

In order to be able to locate the places which limit the transmission capacity of the system, a fibre-optic cable was laid alongside the power cables. The fibre-optic cable sits inside a plastic pipe stripped to the middle cable as it is this cable which usually becomes the warmest. It is then possible to measure the temperature along the cable when it is in operation with specialist equipment connected to the fibre-optic cable, thereby making it possible to locate hot spots which occur along the length of the cable.

Cross-section of cable trench showing the positioning of the fibre-optic cable. Figure 16

Determining the location of hot spots helps to establish the actual transmission capacity of the system as it is these hot spots which govern capacity.

Hot spots along the cable. Figure 50

Determining the temperature along the cable can also be used to calculate the dynamic transmission capacity of the cables. As thermal resistivity depends on moisture in the soil, and as the soil temperature fluctuates according to the time of year, the actual transmission capacity of the system is not constant.

1.5 Transmission Capacity

The starting point for determining the transmission capacity of the circuit is the required static transmission capacity of the system. In other words, the continuous load which the system must be able to tolerate without the stated temperature limits being exceeded. The requirement is a continuous minimum 700 A per circuit.

Under standard conditions the cables which have been supplied have a continuous transmission capacity of 825 A. The temperature limits are 90° C for the conductor and 50° C for the exterior surface of the cable sheath.

Fact box with above info.

In practice, the cables are not buried at a constant depth, for which reason the continuous transmission capacity is less than 825 A. The starting point is a soil temperature of 15° C. As the soil temperature falls to 8° C deeper down, it is more correct to use a temperature of between 8 and 15° C for cables which are deeply buried.

Drawing showing directional drilling beneath road and soil temperature relative to depth. Figure 11

With directional drilling, the cables are pulled through pipes which are then filled with bentonite. As the bentonite is sealed in, it will not dry out within the pipe. Therefore the calculation assumes a maximum temperature of 50° C on the outside of the pipe – not on the outside of the cable. This means that it is often the cable’s conductor temperature of 90° C which is limiting with directional drilling.

Directional drilling. Figures 17 and 18

During normal operation, the cables will not be subjected to the maximum continuous load current for longer periods of time. The lower operating temperature makes it possible to transmit a higher current for several hours before the temperature limits are reached. How much current that can be transmitted depends on the previous load as well as on the ambient temperature and thermal conductivity.

Short-term load. Principle. Figure 8

The cable system is dimensioned with a view to the short-term load capacity being utilised in rare, but not unrealistic situations. The short-term load capacity must not be confused with the overload capacity. The cables have not been dimensioned for temperature limits to be exceeded during short-term loads.

When exceeding the maximum continuous load current, it is normally the temperature limit of 50° C on the outer sheath which limits the transmission capacity of the cable. With very high loads lasting only a short time, it is the conductor temperature of 90° C which is limiting.

Drawing showing maximum temperatures. Figure 51

Equipment for monitoring the system is used to monitor the load current and temperature of the cable, triggering an alarm if the limits are exceeded. The equipment can also calculate the dynamic load capacity and state the maximum load over the next 4 hours or 50 hours.

Example of screen image, dynamic calculation of transmission capacity. Figure 52

1.6 Cable Length and Number of Joints

The cables are supplied on drums. The maximum cable length is 900 m per drum.

The cable routes have the following lengths:

Tebbestrup-Hornbæk:	4.5 km
Katbjerg-Bramslev:	2.5 km
Skudshale-Gistrup:	7.5 km
Total route length:	**14.5 km**

Map showing the three sections. Show the general positioning of the joints.

Two circuits have been laid on all three part sections. In other words, the **total cable length is:**

2 x 3 x 14.5 km = **87 km**

The following number of **joints** have been used:

Tebbestrup-Hornbæk:	5x2x3 =	30
Katbjerg-Bramslev:	3x2x3 =	18
Skudshale-Gistrup:	8x2x3 =	48
Total:		**96**

The following number of **terminations** have been used:

Tebbestrup-Hornbæk:	2x2x3 =	12
Katbjerg-Bramslev:	2x2x3 =	12
Skudshale-Gistrup:	2x2x3 =	12
Total:		**36**

1.7 Casing pipes

When crossing streams and rivers, roads, other pipes and cables, slopes as well as planted areas, the cables are pulled through casing pipes. When crossing small streams, ditches, unsurfaced roads and minor cables, the pipes are laid in open trenches after which the soil is returned. Over broader crossings, or where it is not possible to dig an open trench, the pipes are pulled through a controlled directional drilling.

Three different laying configurations are used for casing pipes:

Drawing showing different laying configurations. Figure 58

The pipes lie flat and sit closely next to one another. The pipes have been laid in an open trench – down to a depth of max. 3 m.

The cables lie in a flat configuration with a spacing of 1 m. For deep directional drillings, one drilling was made for each pipe. The pipes are placed with a spacing of approx. 1 m. This means the cables are able to release heat more effectively.

The pipes sit in a close triangle. The three pipes were pulled through the controlled directional drilling simultaneously.

Drawing showing the sequence of operations. Directional drilling and drawing of 1-3 pipes through the drilling. Figure 10

The pipes are made of polyethylene, a hard plastic. The external diameter of the pipe is 315 mm and the pipe walls are 18.7 mm thick.
When the cables are pulled through the pipes they are filled with bentonite. The bentonite mix solidifies after about a day, becoming stable but without being hard. It must be possible to flush out the bentonite later if a fault occurs on the cable.

Pipes being filled with bentonite. Make a drawing on the basis of previous drawings of directional drillings beneath roads as well as of photographs 101, 102 and 103.

The bentonite has a thermal resistivity of less than 1 kelvin metre per watt.

1.8 Compensation

The 400 kV cables produce reactive power which needs to be compensated out as close to the cables as possible, thereby reducing grid losses. For each circuit kilometre, 10 Mvar of reactive power is generated.

The three cable sections have a total length of two times 14.5 km – 29 km in all. This produces a total of 290 Mvar of reactive power.

Positioning of reactors in the grid. Figure 32

In substation Ferslev a 140 Mvar reactor has been installed which is permanently connected to the Ferslev-Nordjyllandsværket line. The line contains a cable section of two times 7.5 km with a reactive power production of 150 Mvar. When the line is connected and disconnected, the reactor automatically follows as it is directly connected to the line.

Drawing of reactor connection in Hornbæk. Figures 43 and 44

The same procedure is used in cable transition compound Hornbæk where a 100 Mvar reactor has been set up which is permanently connected to the Ferslev-Trige line. This line contains a cable section of two times 7 km with a reactive power production of 140 Mvar.

Drawing of reactor location in Ferslev. Figures 45 and 46

Finally, two connectable 70 Mvar reactors have been installed at substation Ferslev. Preliminary studies have shown that there might be a risk of large voltage jumps in the grid if a 140 Mvar reactor had to be connected. Therefore, together with the permanently connected 140 Mvar reactor, two 70 Mvar reactors have been installed, which also increases flexibility.