# Refurbishment of the Copenhagen Transmission Grid – Project Planning and Execution

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## ABSTRACT

*This paper presents the planning and execution of a cable project in an urban environment where tunnels are not deemed a viable option. Planning during different stages of the project is presented and a number of different obstacles encountered are discussed. It is shown that there are several important parameters which ensures a successful project. 1. Proper and thorough planning 2. Solid cable and cable system design 3. Pragmatic approach to problem solving in the field 4. A good cooperation with the civil contractor who shall solve problems in a practical way.*

## KEYWORDS

Cable project, city, urban, installation, HDD, DTS, case study, civil contractor, planning, time schedule,

## INTRODUCTION

As in many other countries, the transmission grids in the larger cities of Denmark are coming to the end of their designed life as the basic infrastructure in these grids were installed in the same period in time (around 1960-1970). On this background a major project for planning the refurbishment of the Copenhagen transmission grid was initiated with a planned project period ending in the 2030's.

The planning of the first of these projects was started around 2015, with installation work beginning in first half of 2018 and commissioning in the beginning of 2019. This paper presents how the project was planned, executed, commissioned, and it presents the first operational data.

As it will show in the remaining of the paper, all aspects of such a cable project influence each other, and it is therefore difficult to describe project planning as a step by step method as it is in reality an iterative process.
For example; the size of the magnetic field from the cables is of huge importance to the local community, and this magnetic field can be limited by installing the cables in close trefoil formation. However, as the municipality and road authorities only allow for having a couple of hundred meters of open trench at any given time, this method would require an enormous number of joints. This means that a simple requirement of minimizing the magnetic field results in the need for many accessories with all the issues and man hours related thereto. How to solve the magnetic field issue, and how that would affect the installation methods, should therefore undergo an extra iteration.

## REQUIREMENTS FOR CABLE PROJECT

### Geography

A cable project starts by the grid planning department finding a need to connect two nodes in the grid. In this case the grid required strengthening to prepare for the future large-scale refurbishment of the grid, where existing cable links could be taken out of service for longer periods of time. Only by performing a strengthening of the existing grid could such cables be taken out of service without impacting the reliability of supply. This strengthening coincided with the planning of converting a power plant in Copenhagen to biomass from coal, and at the same time move primary production towards district heating instead of electricity.

The new cable system was on this background to connect the two grid nodes Avedøre Værket (AVV) and Amager Koblingsstation (AMK) as shown in Fig. 1.


**Fig. 1: Overview of the grid nodes that had to be connected with this cable project.**

### Time Line

The cable should be in operation by February 1st 2019, which meant that the installation work should be finished in under 1 year. For a cable in a rural area 10.7 km of cable could be installed in less than a ½ year, however in the city environment 1 year for installation was predicted to be very tight though possible.

### Electrical Requirements

The electrical requirements for the cable system are listed below:

- System voltage 132 kV
- Continuous current up to 1200 A
- Yearly average current up to 400 A
- Short circuit rating of 40 kA for 0.5 seconds

## CHOICE OF CABLE ROUTE

In a straight line, the two nodes of Fig. 1 are spaced approximately 9.0 km apart, however a straight route would only be possible with a deep tunnel, and that was ruled out as a possibility very early in the project, as the costs for that are very high. A route with some sort of excavation technique, combined with HDDs should therefore be investigated, meaning going through green areas and in roads. Out of several proposed route alternatives, the route with the least impact on traffic, residents, etc. was found as shown in Fig. 2.

Note especially that the long river crossing of approximately 1 km would have to be done as an HDD as the water is a Natura 2000 area which meant that the cable could not be installed on the seabed. A restriction from the authorities here was further that all work and all machinery had to be away from the eastern landing of this HDD in the bird breading period from March 15 to June 15 every year, as birds use the green area there for nesting. Time plans, work instructions, etc. therefore had to take this into consideration.

Furthermore a 700 meters long HDD had to be done under a golf course to be able to follow the time schedule as planned.

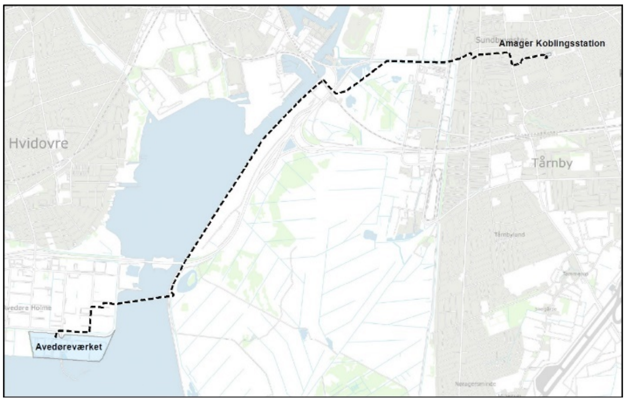


**Fig. 2: Overview of the chosen cable route.**

After many discussions with civil contractors, HDD specialists, communities, authorities, individual residents, local shops, etc. the route shown in Fig. 2 was agreed upon. Instead of 9.0 km the cable route thereby became 10.9 km.

## CABLE AND SYSTEM DESIGN

In order to choose the most optimal cable size, the possible different system configurations/designs have to be investigated. However; in order to come to a proper cable system design the possible installation conditions also have to be known. Therefore: the first clause hereafter describes the anticipated installation conditions, followed by a cable system design description.

### Installation conditions

As for most other cable projects, different parts of the route required different installation methods. These different parts are presented in the following.

#### Normal Installation Conditions

In urban areas the following conditions shall apply for cable system design and dimensioning of cables.

- Cables installed in directly buried ducts
    - Where possible the cables would be installed themselves directly, without ducts.
- Thermal resistivity of 2.0 Km/W
- Ambient temperature of 20 °C
- Maximum cable conductor temperature of 90 °C (due to the high thermal resistivity dry out is expected to be accounted for, and therefore there are no restrictions on the jacket temperature)
- Installation depth of 1.4 meters to bottom of trench
- In trefoil - to limit the magnetic field above ground

These conditions sum up to a cross section of the cable trench shown in Fig. 3.

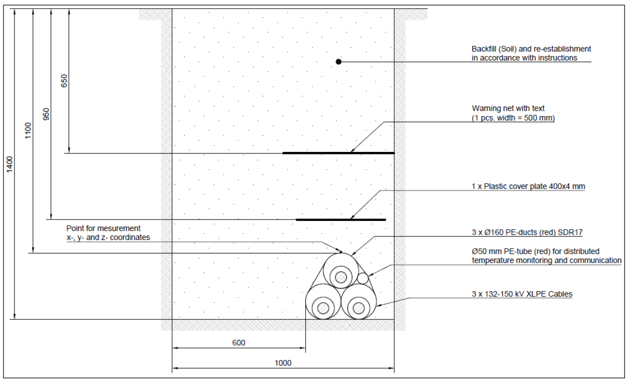


**Fig. 3: Standard cable trench when installing cables in an urban/populated environment.**

To limit the magnetic field from the cable system as much as possible, and to minimise the width of the cable trench, the diameter of the ducts had to be as small as possible, which meant that pulling with winch wire was not deemed possible. Instead the cables would be installed with the WatuCab technique where the cables are flushed into the pipes/ducts with water pressure.

#### Horizontal Directional Drillings

For crossing under the river and under the golf course, the HDD was created as shown in Fig. 4.

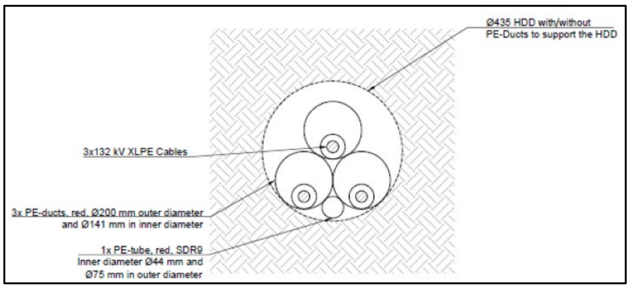


**Fig. 4: The HDDs were chosen to be done as on common drilling for all three phases. This ensured a balanced cross-bonding system and a less risky project execution (due to fewer pilot drillings).**

Due to the geotechnical conditions at the HDDs, it was necessary to have the long HDDs going to a maximum depth of approximately 30 meters.

It is important to emphasize that it was planned to install the HDDs in flat formation with a phase separation around 3 meters, such that maximum ampacity of the cables could be ensured. However; such a layout where one minor section would be flat formation and the other two would be close trefoil formation compromised the balance of the cross-bonding system to such an extent that it was estimated that several hundreds of amperes should be expected to flow in the cable screens at rated conductor current.

The possibility of installing the two other minor sections around the long HDDs in flat formation was also investigated, as this is the other possibility for obtaining a well-balanced cross-bonding system. However, this would require a large phase spacing in the normal trench, which would increase the installation costs there. Furthermore, the HDD contractor was consulted for advice, and it was found to be a large project risk to make three separate (but smaller) HDDs instead of one common (but large) HDD.

Compiling all this information resulted in choosing to install all cables in trefoil formation including making one common HDD wherever possible.
However, crossing railways was planned as flat formation HDDs as the authority process for applying and receiving for the permit for performing the larger trefoil HDD was much longer than for the smaller flat formation HDDs, and thus a common large HDD would not be possible within the timeframe of the project.

### Joint Bays

Similar to the normal cable route, the size of the joint bays should be limited to the furthest possible extend and be open as short time as possible. It was therefore chosen to do the jointing of the cables above ground level in a jointing container straddling across the cable trench. After jointing, the cables would be lowered into the cable trench with the overlength being snaked horizontally into the joint bay and cable trench, Fig. 5.

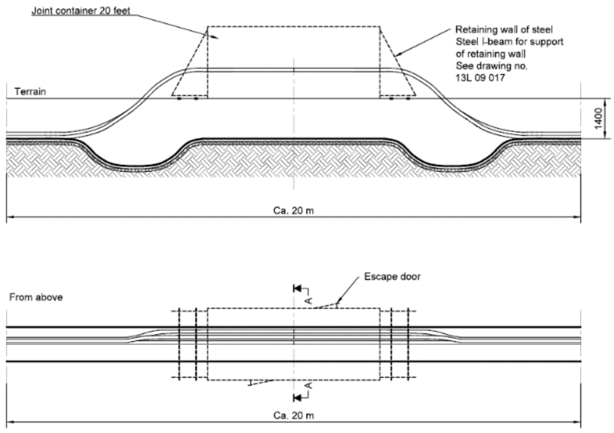


**Fig. 5: Side view sketch of a cable joint bay. The jointing is seen to be performed over ground, where after cables and joints are lowered into the joint bay.**

### Overall Layout

The overall layout of the cable system installation methods is presented in Fig. 6

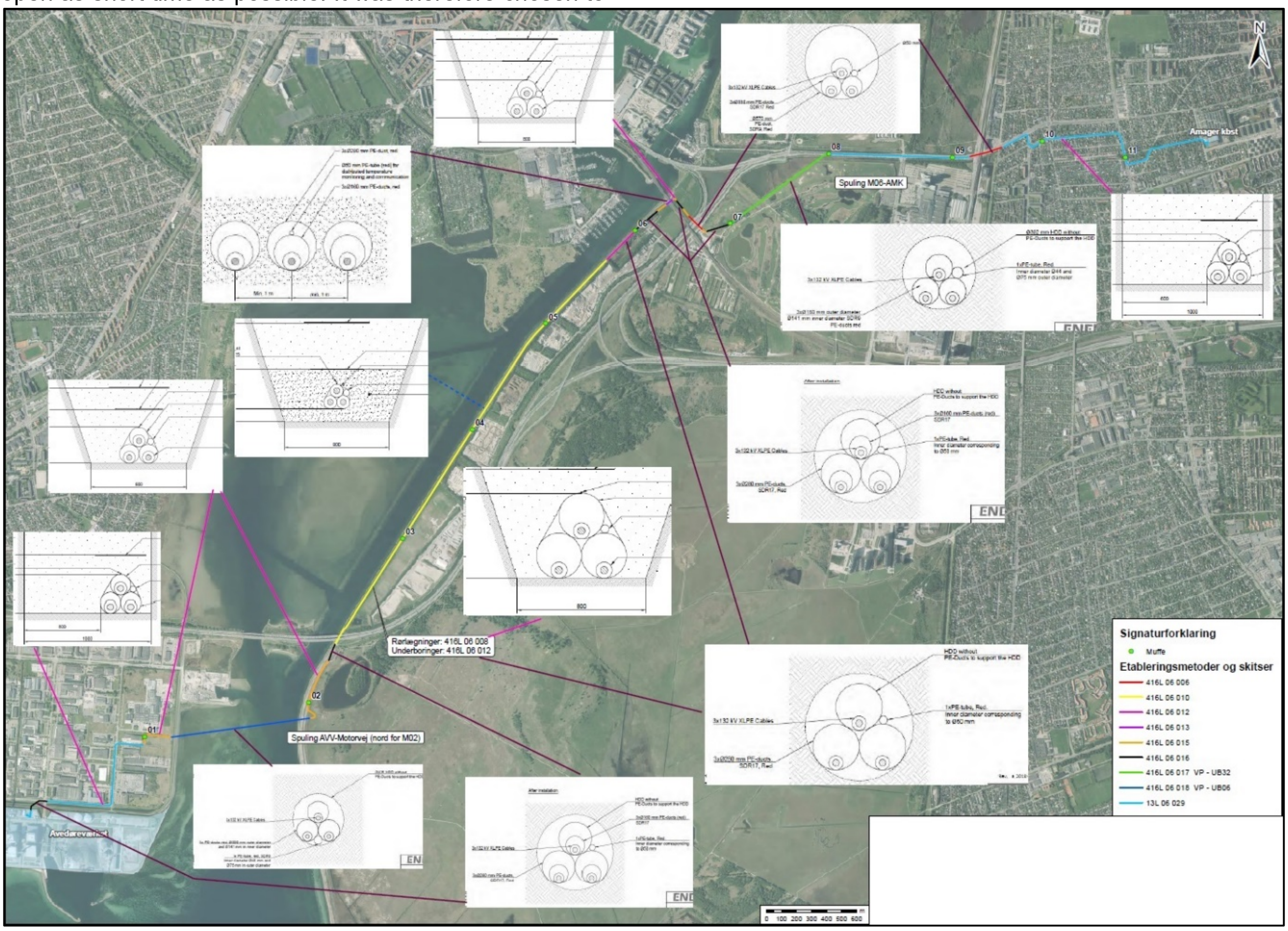


**Fig. 6: Summary of the installation methods used along the route.**

## Cable System Design

As for all other cable systems in Denmark, the AVV-AMK cable should be designed so that the total CAPEX and OPEX costs are optimised. Therefore; the cable system was designed as cross-bonded, to minimise cable size and losses during operation.

In rural areas, direct cross bonding is used to the furthest possible extend to limit the number of components (both direct and maintenance costs are affected by this) and to reduce the amount of farmland which is tied up by having vaults for the link boxes. However; in urban areas land is not used for agricultural or similar purposes and it is therefore possible to have link box vaults brought to the ground surface without disturbing the community. Furthermore; the use of link boxes instead of direct cross bonding eases fault localisation, and because of these reasons, urban cable projects perform cross-bonding through link boxes.

On this background the cable system design looks as shown in Fig. 7.

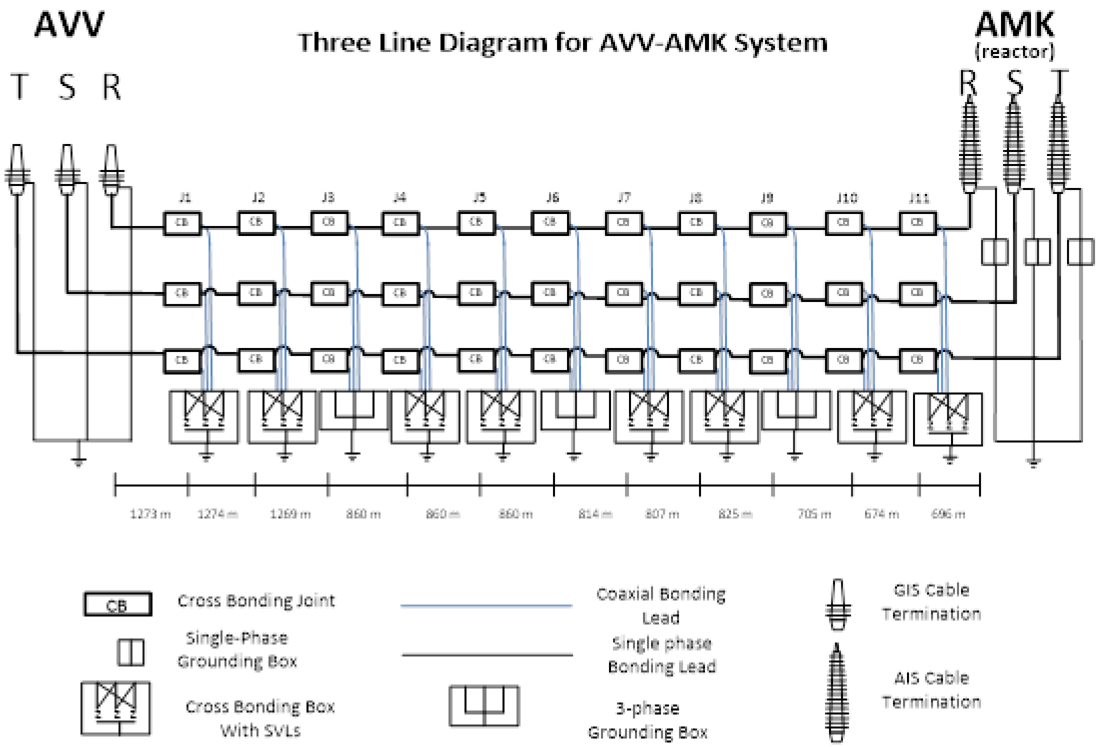


**Fig. 7: Three-line diagram of the cable system. It is seen that cable screens are cross-bonded through link boxes and that the cable section lengths differ along the route in order to ensure a balanced cross-bonding system.**

## Cable Design and Accessories

Due to a significant time pressure, the cables for this project had to come out of a framework agreement which contained aluminium conductor cables of all cross sections specified in IEC 60228 from 800-2000 m$^2$.

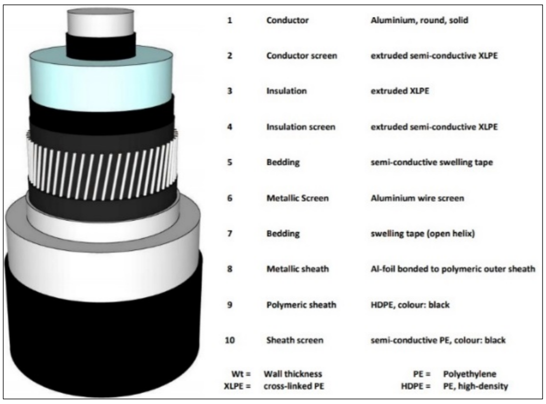


**Fig. 8: Schematic of the installed cable.**

When performing ampacity calculations according to the IEC 60287 series, for the air-filled ducts sections, the ampacity for the largest cable of 2000 mm$^2$ ends up being 893 A which is well below the 1200 A that was the wish of the grid planning department. The discussion on how to handle the requirement for ampacity vs. time frame ended with the conclusion to accept the lower ampacity as a trade-off for a quick commissioning.

It was on this background agreed between all relevant stakeholders to install the 2000 mm$^2$ cable, Fig. 8.

## Magnetic Field

As stated, the magnetic fields have to be minimised, but not only should they be small, they should to a reasonable extend be kept lower than 0.4 μT in people's houses, in schools, in child day-cares, etc., measured in a height of 1.0 meter above ground.

When choosing the cable route, the magnitude of the magnetic field, seen as a yearly average, was taking into account. The magnetic field over the cable system and on each side of the cable system is given in Fig. 9.

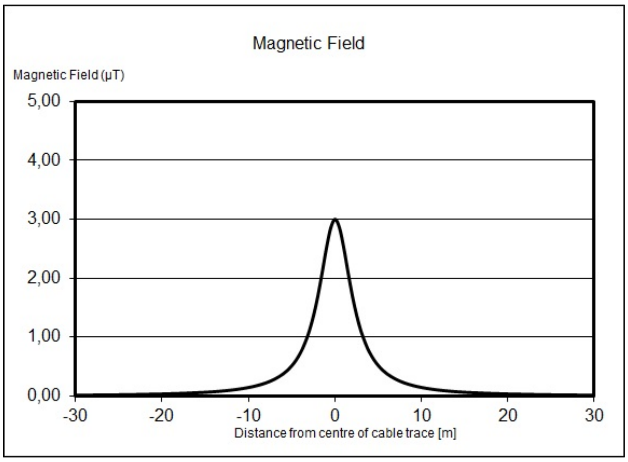


**Fig. 9: Yearly average magnetic field as a function of the distance from the centre of the cable route. At 6.0 meters distance 0.4 µT is reached which is the target maximum value where people live or children are staying.**

Fig. 9 shows that the magnetic field reaches 3.0 µT right above the cables, however 6.0 meters away from the cable route the magnetic field has fallen to 0.4 µT. Therefore houses, schools, etc. should be located not closer than 6.0 meters from the centre of the cable route.

## PROJECT EXECUTION

A significant amount of resources was put into planning in order to ensure project execution to be running according to timeline and plan, however even the best planning can run into troubles when hitting the real world. A couple of these issues are presented in the following clauses, and it is discussed how a close collaboration with a reliable civil contractor is important to find practical solutions in the field while performing e.g. excavation work.

Some of the first work to be started was the two long HDDs. Because the same HDD machine, Fig. 10, should be used for both HDDs, it was important not to delay the start of this work.

**Fig. 10: The big HDD machine was needed for performing the more than 950 meters HDD drilling.**

The HDD under the golf course was exposed to partly lying on an old military shooting range, meaning that there was a risk of UneXploded Ordnances (UXOs). Proper shielding of personnel from possible explosions was therefore made where several concrete and metallic barriers were installed between all personnel and he drilling zone, Fig. 11.

**Fig. 11: Protection from UXOs when performing HDD drillings in an old military shooting range.**

This first long HDD proved to be more difficult than expected and the timeline therefore floated from 50 days to 80 days of drilling.
Similarly, because the location was not too far from HDD number one, the second drilling was delayed from the planned 60 days to 90 days. These delays were part of the reason for getting an overall delay in the project time schedule.

Not only must projects in city areas expect to run into longer HDD drilling times, it must also be expected to encounter surprises along the trenching route. In this project such surprises were

Distribution lines unaccounted for (or wrongly registered) in public registers, Fig. 12.

**Fig. 12: Digging a hole is not so simple in an urban environment where a lot of different distribution lines are fighting over the same corridors.**

**Fig. 13: At certain places it might be necessary to install the cables very deep, in order to ensure clearance distances to other infrastructure.**

Crossing infrastructure in target depth, Fig. 14.

**Fig. 14: Problematic installation when crossing existing infrastructure which occupies the same depth as the cable system.**

Fig. 11 to Fig. 14 presents that practical solutions are necessary, even though unfavourable, when performing cable installation in a densely populated area with a lot of existing underground infrastructure.

Having installed the ducts as described, the cables were, as stated, flushed into the ducts, Fig. 15. With this technique the cable is pulled by a water pressure powered pig while at the same time being pushed by mechanically driven belts. In this way long installation lengths can be reached while the forces exerted on the cable are kept low.

**Fig. 15: Installation of cables using water pressure and caterpillar.**

## CABLE SYSTEM COMMISIONING

After installation, the cables were subjected to a HiPot test with 1.7x$U_0$ for 1 hour. This was done using Resonance Test Sets (RTSs) where the frequency is adapted to fit the eigenfrequency between the cable capacitance and the test set's inductance. Furthermore, Partial Discharges (PDs) were measured at the terminations as part of the HiPot Site Acceptance Test (SAT). All cables and accessories in the system passed without issues.

## THE FIRST FEW WEEKS IN OPERATION

The cable was commissioned in the middle of March 2019, meaning a delay of 1½ month compared to the original time schedule, however it is considered that the time was well spent as high HSE standards were enforced and the cable system passed the commissioning test without issues.

Fig. 16 shows the current over time in the first test period which lasted 4 days and 4 hours. It is seen that the loading is very high compared to other cables in the transmission system, but under the rated current.

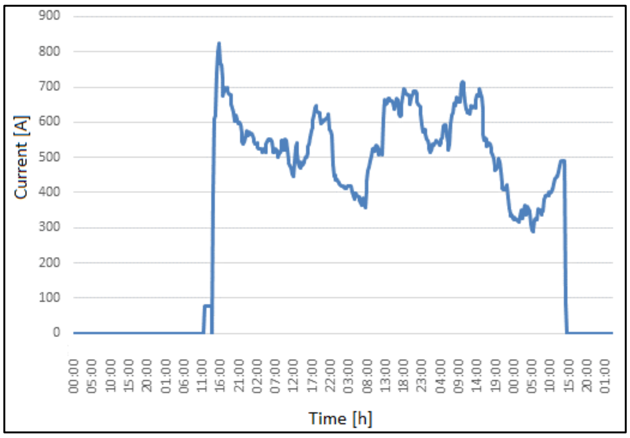


**Fig. 16: Loading on cable after commissioning.**

Fig. 17 shows the temperature along the cable, of the unloaded cable (blue) and the cable after the load in Fig. 16 (brown). Temperature is measured with a Distributed Temperature Sensing (DTS) equipment.

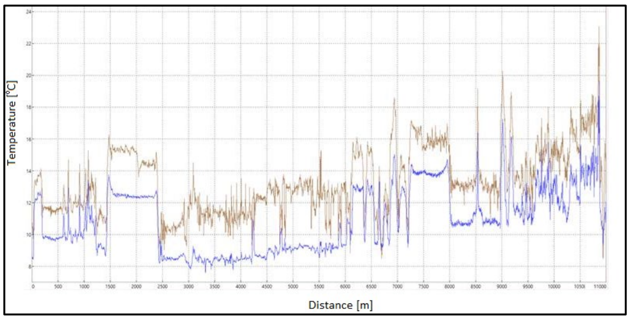


**Fig. 17: Temperature of the unloaded cable (blue) and the cable after four days of heavy load (brown).**

The temperature profile clearly identifies the two long HDDs as they (during the wintertime) have a higher base temperature than the rest of the cable route. A significant amount of information is stored in this data and is awaiting to be extracted. It is e.g. planned to perform online Dynamic Line Rating (DLR) on this cable in order to ensure cable integrity and utilise the cable system to the greatest possible extend.

## CONCLUSION

This paper has presented that proper planning can drive a complex cable project on a tight deadline. Even though this cable project was commissioned approximately 1½ month after original schedule this is seen as a major achievement, timewise, not least because the project was executed with a high HSE standard and quality.

The paper has shown that many difficult obstacles must be expected for such cable projects, and that it is vital to have a pragmatic way to resolve the issues.

The paper has presented the entire project from start to end, from planning stage to the first operational data, and it is seen that the cable was in high demand as the loading instantly increased to rated current after commissioning.