Energimyndigheten

VATTENFALL

Offshore Cable Installation - Lillgrund

Lillgrund Pilot Project

January 2009

Photo: Hans Blomberg +46 70 550 0121

Lillgrund Wind Power Plant 2006-12-18 6725
Submarine export cable installation. Pull-in at landfall.

Type of document	Document identification	Rev. No.	Report date	Project No.
REPORT	3_2 LG Pilot Report	1.0	January 29, 2009	21858-1

Author	Project name
Oscar Unosson	Lillgrund Pilot Project
Customer	Reviewed by
Vattenfall Vindkraft AB	Åke Larsson
	Approved by
	The Reference Group

Distribution	No. of pages	No. of appendices
The Swedish Energy Agency	30	0

PREFACE

Vattenfall's Lillgrund project has been granted financial support from the Swedish Energy Agency and Vattenfall will therefore report and publish experiences and lessons learned from the project. This report is compiled in a series of open reports describing the experiences gained from the different aspects of the Lillgrund Wind Farm project, for example construction, installation, operation as well as environmental, public acceptance and legal issues.
The majority of the report authors have been directly involved in the Lillgrund project implementation. The reports have been reviewed and commented by a reference group consisting of the Vattenfall representatives Sven-Erik Thor (chairman), Ingegerd Bills, Jan Norling, Göran Loman, Jimmy Hansson and Thomas Davy.

The experiences from the Lillgrund project have been presented at two seminars held in Malmö (4th of June 2008 and 3rd of June 2009). In addition to those, Vattenfall has presented various topics from the Lillgrund project at different wind energy conferences in Sweden and throughout Europe.

All reports are available on www.vattenfall.se/lillgrund. In addition to these background reports, a summary book has been published in Swedish in June 2009. An English version of the book is foreseen and is due late 2009. The Lillgrund book can be obtained by contacting Sven-Erik Thor at sven-erik.thor@vattenfall.com.

Although the Lillgrund reports may tend to focus on problems and challenges, one should bear in mind that, as a whole, the planning and execution of the Lillgrund project has been a great success. The project was delivered on time and within budget and has, since December 2007, been providing 60 000 households with their yearly electricity demand.

Sven-Erik Thor,
Project Sponsor, Vattenfall Vindkraft AB
September 2009

DISCLAIMER

Offshore Cable Installation - Lillgrund

SUMMARY

This report describes the installation method and the experiences gained during the installation of the submarine cables for the offshore wind farm at Lillgrund. The wind farm consists of 48 wind turbines and is expected to produce 0.33 TWh annually.

Different aspects of the installation, such as techniques, co-operation between the installation teams, weather conditions and regulatory and environmental issues are described in this report. In addition, recommendations and guidelines are provided, which hopefully can be utilised in future offshore wind projects.

The trenches, in which the submarine cables were laid, were excavated weeks before the cable laying. This installation technique proved to be successful for the laying of the inter array cables. The export cable, however, was laid into position with difficulty.

The main reason why the laying of the export cable proved more challenging was due to practical difficulties connected with the barge entrusted with the cable laying, Nautilus Maxi. The barge ran aground a number of times and it had difficulties with the thrusters, which made it impossible to manoeuvre.

When laying the inter array cables, the method specification was closely followed, and the laying of the cables was executed successfully.

The knowledge and experience gained from the offshore cable installation in Lillgrund is essential when writing technical specifications for new wind plant projects.

It is recommended to avoid offshore cable installation work in winter seasons. That will lower the chances of dealing with bad weather and, in turn, will reduce the risks.

SAMMANFATTNING

I denna rapport beskrivs genomförande och erfarenheter från sjökabelinstallationen vid Lillgrund vindkraftpark. Vindkraftparken består av 48 vindkraftverk och förväntas årligen producera cirka 0,33 TWh.

Rapporten behandlar olika aspekter av kabelinstallationen, såsom teknik, samarbete mellan arbetsgrupper, väderförhållanden samt myndighetskrav. Rapporten innehåller också ett antal råd och rekommendationer och förhoppningsvis ska dessa kunna tillämpas i framtida havsvindprojekt.

Sjökablarna förlades i kabeldiken, vilka man grävde åtskilliga veckor innan själva förläggningen ägde rum. Denna förläggningsteknik fungerade bra för det interna kabelnätet. Förläggningen av kabeln mellan transformatorplattformen och land, den s.k. exportkabeln, var dock betydligt mer komplicerad.

Den huvudsakliga anledningen till problemen med förläggningen av exportkabeln var relaterat till det kabelförläggningsfartyg som användes. Kabelförläggningsfartyget fick sina propellrar skadade vid en grundstötning och kunde därmed inte manövreras.

Vid förläggningen av det interna kabelnätet följdes metodbeskrivningarna mycket noga och detta resulterade också i att förläggningen gick mycket bra.

Den kunskap och erfarenhet som erhållits från kabelförläggningsarbetena vid Lillgrund utgör ett mycket värdefullt underlag för tekniska specifikationer i kommande havsvindprojekt.

En klar rekommendation baserad på erfarenheterna från Lillgrund är att undvika kabelinstallationsarbete under vintersäsongen. Detta för att minimera stilleståndstid på grund av väder samt arbetsmiljörelaterade risker.

TABLE OF CONTENTS

1 INTRODUCTION

The purpose of this report is to describe the installation method and the experience gained during the installation of the submarine cables for Lillgrund offshore wind farm.

The report explains the different aspects of installation, such as the techniques used, the cooperation between the different subcontractor teams, the impact of weather conditions and regulatory and environmental issues. It also provides recommendations and guidelines, which can be applied in future offshore wind plant projects.

2 THE LILLGRUND OFFSHORE WIND FARM

Chapter 2 includes general project information as well as the organisational chart for the cable installation and an overview of the cable system.

2.1 General project information

Vattenfall AB has constructed an offshore wind farm at Lillgrund, in the Öresund Sea. The Lillgrund offshore wind farm was under construction between spring 2006 to the end of 2007 when it was completed. The generation from the wind farm is expected to be in the region of 0.33 TWh annually, which corresponds to the electricity demand of more than 60 000 homes. The wind farm is located off the Swedish coast in an area with shallow water, see figure 1.

Figure 1. Map over Lillgrund in the Öresund Sea

The wind farm consists of 48 wind turbines and one large transformer, for a total of 49 offshore platforms. There were two main suppliers and Siemens Windpower supplied the wind turbines and electrical system. Phil/Hochtief was the main supplier of the gravity base structure platforms, which will not be addressed in this report.

2.2 Cable installation organisation

The wind turbines were purchased from Siemens Wind Power, and the contract included high voltage cables in the form of internal grid cables and export cable. The high-voltage cables were supplied by ABB High Voltage Cables. ABB also used subcontractors for the installation work, see figure 2.

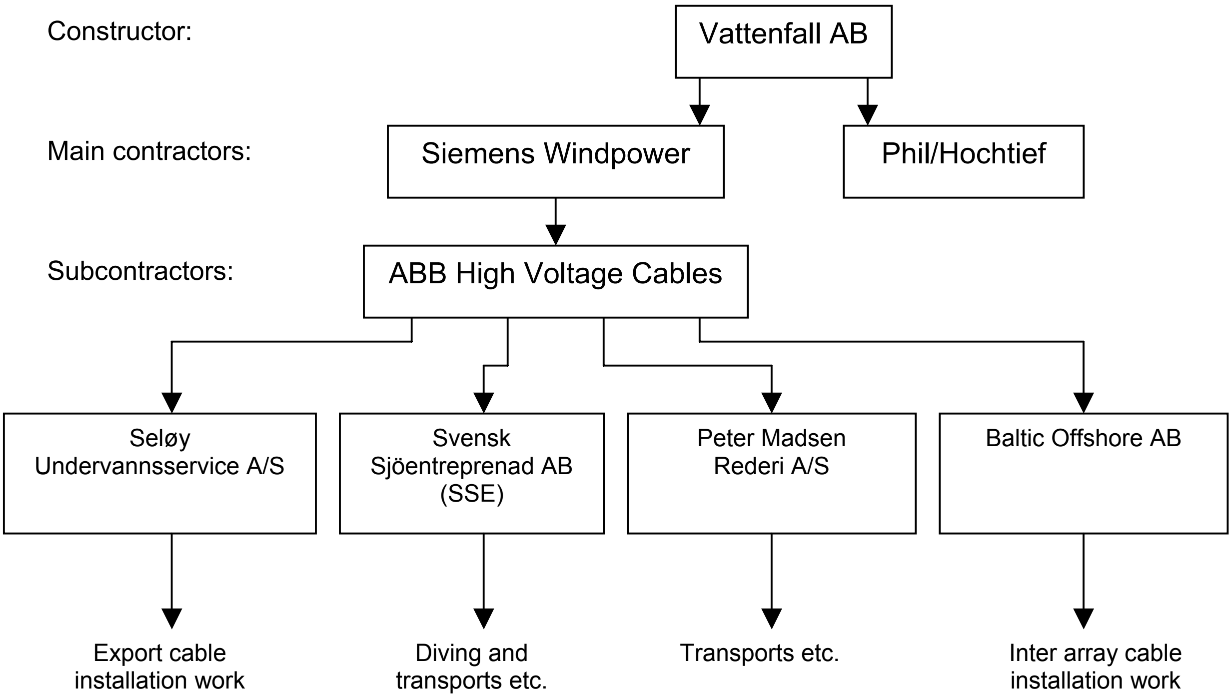

Figure 2. Schedule over the contractors

Due to the importance of the submarine cables and the complexity of the installation Vattenfall AB had on-site supervision.

2.3 Lillgrund cable system

The offshore wind farm electrical network includes a series of inter-array cables and an export cable, see figure 3.

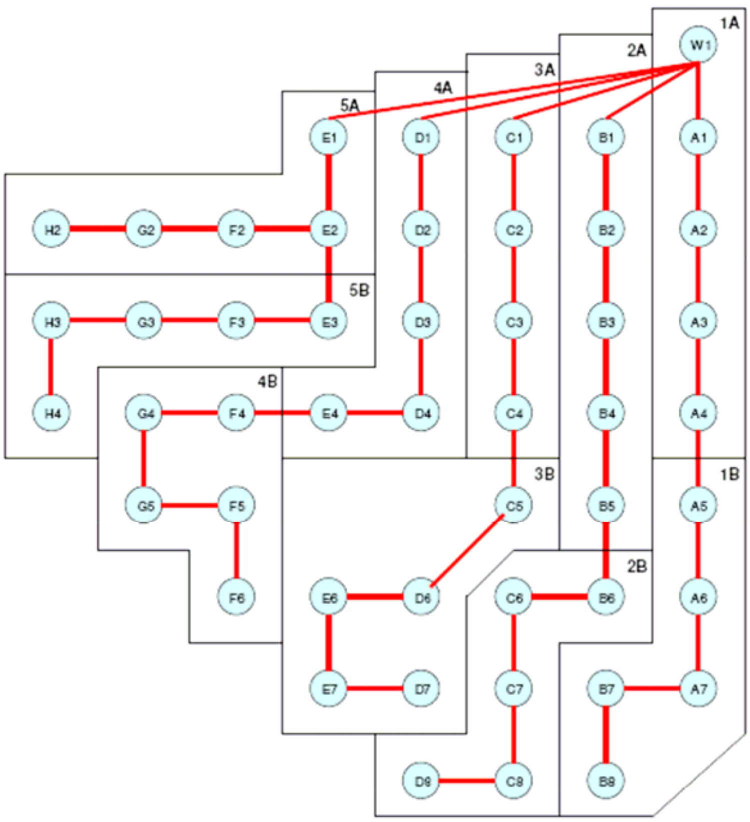

Figure 3. Inter-array cable layout

Voltage levels are 36 kV for inter-array cables and 145 kV for the export cable. The inter-array cables connect the wind power generators with the transformer platform, W1. The inter array cables are supplied in three different cross sectional sizes 95 mm^2, 185 mm^2 and 240 mm^2. The closer to the transformer platform the larger the dimension of the cable, as shown in figure 4 below.

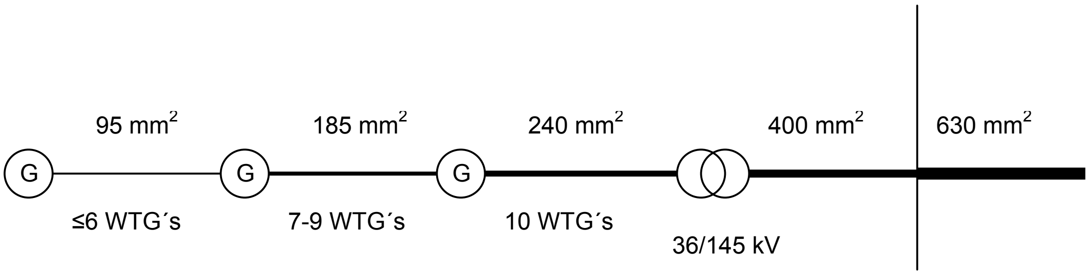

Figure 4. Cable Schematic

There are 48 inter array cables in total. The length of the cables vary, with 15 of the cables each approximately 350 meters, 28 of the cables approximately 450 meters and 5 cables up to 1500 meters. The export cable connects the transformer platform with the substation in Bunkeflo. The export cable is divided into a 7 km submarine cable with a size of 400 mm^2 and a 1,7 km land cable with a size of 630 mm^2. The submarine cables include an integrated optic cable. The onshore cable includes a total of 4 separate cables, three AXLJ 1 x 630 mm^2 as well as an optic cable.

2.3.1 Cable design

The different cable types used in Lillgrund are described below:

FXCTV 3 x 95 mm^2 36 kV. The cable consists of 3 round, solid copper conductors, each 95 mm^2. Outside the insulation that surrounds the conductors is a metallic screen of copper wires. The cable is rated for 36 kV and armoured with 4 mm thick galvanised steel wires. The entire cable has a diameter of 106 mm and a weight of 16 kg/m.

FXCTV 3 x 185 mm^2 36 kV. Similar design to FXCTV 3 x 95 mm^2 36 kV. The entire cable has a diameter of 116 mm and a weight of 19 kg/m.

FXCTV 3 x 240 mm^2 36 kV. Similar design to FXCTV 3 x 95 mm^2 36 kV. The entire cable has a diameter of 120 mm and a weight of 22 kg/m.

FXBTV 3 x 400 mm^2 145 kV, figure 5. Instead of metallic screen of copper wires there is a metallic sheath of lead alloy. The entire cable has a diameter of 166 mm and a weight of 56 kg/m.

Figure 5. FXBTV 3 x 400 mm^2

AXLJ 1 x 630 mm^2 145 kV. The cable consists of 1 round, compact aluminium conductor with a cross sectional area of 630 mm^2. Outside the insulation that surrounds the conductor there is a metallic screen of copper wires. The cable is not armoured. The entire cable has a diameter of 74 mm and a weight of 5,9 kg/m.

GASLMLV fibre optic cable. The cable, which is included in the offshore cables, consists of 48 fibres.

3 SUPERVISION

This report is mainly based on Vattenfall's supervision of the cable installation work activities. The installation work activities were reported to the Vattenfall's project manager for the electric systems. The scope of the supervision is detailed below.

3.1 Export cable

Due to the vital importance of the export cable, the loading of the cable onto the barge, carried out at ABB's High Voltage Cables harbour was closely supervised by Vattenfall. In addition, the installation of the export cable between Bunkeflo and Lillgrund was supervised both from the barge Nautilus Maxi and from on-shore.

- Supervision onboard the barge, see chapter 3.2 under supervision onboard C/S Pleijel
- On-shore supervision of the cable pull-in. The focus for the on-shore supervision was to observe how the cable reacted to the influence of wind, water current, etc during pull-in. The cable was also influenced by how it was pulled on the rollers and submerged into the trench.

3.2 Inter Array cables

The supervision of the cable installation consisted of participating as close as possible onboard C/S Pleijel, M/S Peter Madsen and on the foundations.

- The supervisor onboard C/S Pleijel was positioned at the bow wheel, close to the cable path, and on the bridge. From the bow, the angle at which the cable went into the water could be supervised. In addition, it was very important to ensure that the cable was not too stretched or too loose, and that the cable did not get stuck or kinked. It was also important to ensure that the cable coils did not get twisted. The entire operation could be supervised from the bridge on C/S Pleijel and the communication between the crews was observed closely.
- Supervision onboard M/S Peter Madsen took place on the bridge and in the divers area. On the bridge, the navigation, with the help of the spuds, was supervised. From the divers place the real-time, post-lay cable survey was supervised.
- At the foundations, the cable pull-in and the handling of the cable end was being supervised.
- The supervisor of each vessel reported to Vattenfall´s project manager in charge of the electric installations.

4 METHOD DESCRIPTION – OFFSHORE CABLE INSTALLATION

The offshore part of the export cable installation consisted of trenching, laying, pull-in and burying. The last 300 meters of the export cable, which was to connect to the transformer platform, was installed on the seabed temporarily until the transformer platform had been positioned.

The offshore export cable installation was carried out using the barge Nautilus Maxi. First, the cable was pulled to shore from the barge. Then, all but the last 300 meters of the cable was laid into the trench. The remaining was to be connected to the transformer platform.

The inter array cable installation was performed with the help of two ships, C/S Pleijel and M/S Peter Madsen, and their workboats. C/S Pleijel was responsible for laying down the inter-array cable between the foundations and M/S Peter Madsen was used as the base for the divers during the cable pull-in and the post-lay inspection. M/S Peter Madsen also transported ABB team, tools and material between the foundations.

4.1 Procedures

4.1.1 Survey prior trenching

A survey of the chosen cable route as well as the corridor of around 30 meters each side of the route was carried out before trenching, see figure 6.

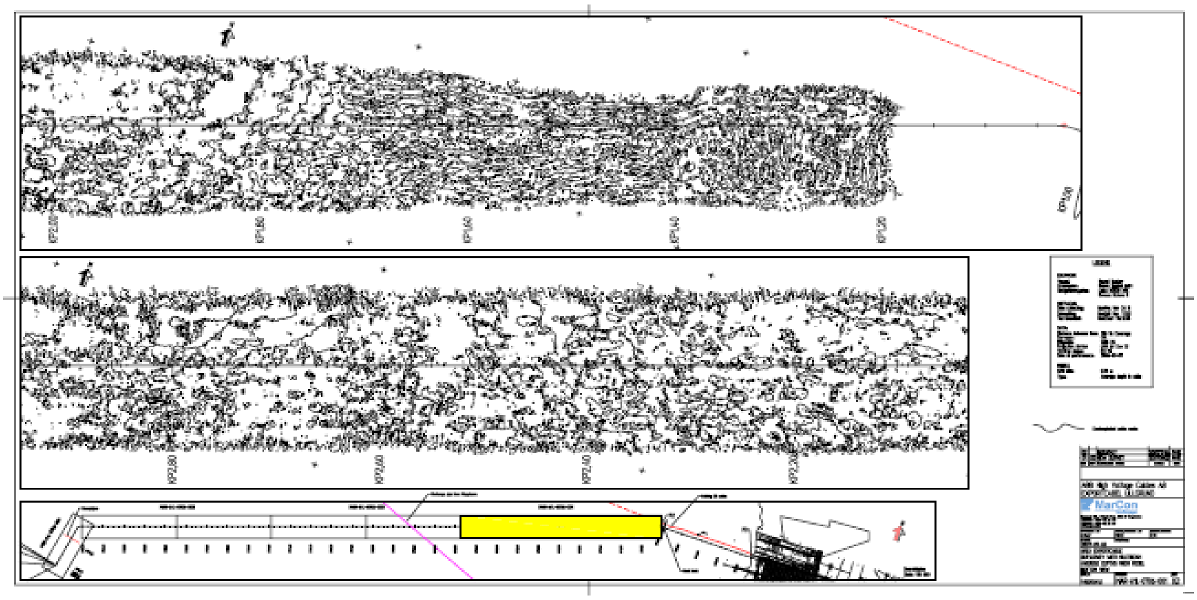

Figure 6. The result of the survey in the form of equidistance curves

The aim of the survey was to investigate if there were any obstacles such as wrecks, cabling or piping which could potentially interfere with the trenching and laying. A marine vessel (M/V Sound Seeker) equipped with multi-beam echo sounding system carried out the survey. Near shore where the depth was below 2 meters (for 1000 meters) a diver surveyed the cable route and corridor.

A similar survey was carried out after the cable installation and backfilling. The authorities required a maximal seabed divergence on 0.3 meters between the survey prior trenching and after backfilling.

4.1.2 Trenching

The trenching was divided into offshore trenching and near shore trenching. In water depths of more than 1 meter, trenching was defined as offshore trenching. The radiuses of curves were not allowed to be less than 50 meters. The trench depth had to be 1 meter below seabed, and the width of the bucket was 1.5 meters. The excavated material was placed on only one side of the trench to minimise the risk of grounding. During excavation the bucket was kept as close as possible to the seabed to minimise material spill. There were restrictions relating to working in inclement weather conditions, due to the risk of encountering archaeological artefacts, hazardous materials etc.

4.1.3 Soil

Near shore, the surface layer soil consisted of postglacial sand covered by mud. Offshore, the soil consisted of bolder clay, which was very stiff, covered in some areas with a thin layer of postglacial sand. There were also boulders of up to 2-4 meters in diameter and a couple of deviations in cable route due to these obstacles.

4.1.4 Cable laying

The cable was stretched to ensure a high tension when it was laid down in the trench. It was important to minimise the tension at turning points so the cable stayed in the trench. The tension was adjusted by the control system on the barge. A ROV (Remotely Operated Vehicle), and near shore, a diver confirmed the touch down of the cable in the trench. A diver carried out the post-lay inspection for the inter-array cables.

Using inflated airbags, the export cable was pulled-in approximately 1000 meters onto the shore. The inter-array cables were pulled-in to the foundations.

4.1.5 Weather limitations

The pull-in operation to shore required a 48-hour weather window to allow time for everything from the approval of the pre-lay survey to the post-lay inspection. Pull-in at the caisson required a weather window of 6 hours. Marine operations cannot be executed during bad weather. The weather limitations that must be adhered to when performing the export cable pull-in operation are outlined below:

- Wind (max 7 m/s)
- Waves (max 0.6 m)
- Current (max 0.5 m/s)
- Visibility (min 300 m)

The weather limitations depend on the type of operation carried out, and therefore may vary for surveying, trenching, cable laying, carrying out ROV-operations and backfilling.

4.1.6 Diving restrictions

Diving operations were planned and executed according to the regulations stated in AFS 1993:57 Dykeriarbeten issued by the Swedish National Work Environmental Authority.

5 EXPORT CABLE

This chapter is divided into two parts, cable loading in Karlskrona and cable laying from Bunkeflo to Lillgrund.

5.1 Cable loading

5.1.1 Arrangement at the factory

November 30, 2006:

The submarine export cable was loaded onto the barge Nautilus Maxi from the cable manufacturer located in Karlskrona. The cable was coiled on the asphalt outside the factory using a storage space approximately 400 metres from the quay, figure 7.

Figure 7. The cable engine hanging in the crane pulled the coiled export cable from the storage space. As can be seen above, the cable is transported 400 metres on conveyor idlers.

The loading consisted of many elements. On shore the export cable was equipped with a cable engine at each end of the cable, one at the storage space and one at the quay, figure 8. The onshore cable engines were operated one at a time. Behind each cable engine there was a slack on the cable that is constant at the right velocity. On the barge there were two additional pulling devices before the cable coiled onto the turntable.

Figure 8. In a tent on the quay a second pulling device was placed. In the tent the cable was marked at exact lengths.

Because of the necessary slack behind the cable engine the barge had to be moored approximately 15 meters from the quay, figure 9.

Figure 9. To the right of the picture is the slack from the quay. On the barge are the pulling devices, the capstan and the vespa on the “gooseneck”.

5.1.2 Loading

There were no problems on shore during the loading. The cable engines were constructed for the purpose of pulling such large cables and the two men who controlled the cable engines had a comfortable margin on the slacks.

Initially, the first loading issue was to get the cable around the capstan wheel. When that succeeded, the ingoing cable wedged the outgoing cable. The cable also seemed to be too stiff for the capstan. The wheel should therefore optimally have had a bigger diameter to ensure that the friction would be enough to help the vespa pull the cable onboard. After getting the cable around the capstan, the next issue was the vespa. The vespa turned out to be too small for the cable diameter. When the vespa was adjusted to allow the cable through, it didn’t receive enough power to provide the required tension to the cable. Though the first layer on the turntable went well, the lack of tension on the following layers showed that adjustments needed to be made.

December 1, 2006:

After attempts using harder bindings around the vespa as well as a higher hydraulic pressure, an electric motor was installed with a wheel which pressed onto the cable at the capstan, figure 10.

Figure 10. The motor installed with the wheel pressing onto the cable at the capstan.

December 2, 2006:

With the help of the electric motor and wheel, the whole length of the cable was loaded onboard. An average speed of loading of 5-6 meters per minute was planned, but at times the speed was exceeding 10 meters per minute. When the loading was finished, a fibre test confirmed that the tension in the cable was accurate.

5.1.3 Pre-laying and bad weather conditions

The issues identified during loading raised questions about the ability to lay and reload the cable in the case of bad weather conditions. Carrying out a pre-laying exercise in a neighbouring archipelago solved this.

Before the pre-laying exercise was carried out, a new construction was added to the “gooseneck” which included an extra vespa. The new construction was an extension of the “gooseneck” where the vespa was built-in, figure 11.

Figure 11. An extension was built on the “gooseneck” where the vespa was built-in.

December 3, 2006:

A practice run with about 50 meters of cable was pre-laid, on a similar depth as Lillgrund (10 meters). The practice run in the archipelago worked out very well. Due to the difficulties loading the cable the barge had been delayed for about two days but was now finally ready for the transit to Klagshamn.

December 3-15, 2006:

During this particular period there were poor weather conditions on the south coast of Sweden. The barge had to wait in Karlskrona an additional few days for better weather. When the barge finally sailed to Klagshamn, the weather conditions were too bad for cable laying and the barge had to wait in the harbour of Limhamn.

5.2 Pull-in of the cable

December 16, 2006:

After two weeks of waiting for better weather, it was finally time to make the pull-in of the export cable. The weather forecast predicted acceptable weather conditions for the next couple of days, so the barge went out to the starting position.

December 17, 2006:

The weather made a turn for the worse and made it impossible to guarantee a safe pull-in.

December 18, 2006:

The weather conditions improved and an attempted pull-in of the cable was approved. Although the barge had moved slightly from its position due to the wind, this did not pose a problem for the pull-in. The pull-in took place with the use of inflated airbags, which took the cable towards shoreline, figure 12.

Figure 12. Inflated airbags took the cable towards shoreline.

In front of the cable, a small workboat was used to keep the course towards the excavators. The tide was higher than expected, so the excavators could not reach as far as planned. Instead, a larger workboat was used to reach the steel wire with the cable. The wind came from the back but the water currents came from the starboard side. The steel wire was too heavy for the workboat. A bigger workboat managed to reach the steel wire with the end of the cable. When the Chinese finger was secured to the steel wire, the excavator and an onshore winch fulfilled the pull-in, figure 13.

Figure 13. The cable pull-in made by the excavators and a pull-in winch. A bigger workboat and two divers were also used.

Near shore, the cable was pulled on rollers because of the heaviness of the cable, figure 14.

Figure 14. The cable pull-in at the shoreline made by the excavator and a pull-in winch.

When the pull-in was ready the cable was submerged into the pre-excavated trench.

December 19, 2006:

The floating bags that were used during the submerging of the cable were not disposed of immediately, which caused temporary debree scattered along the shoreline. Divers walked or swam the whole shoreline in the bay to collect floating bags, figure 15.

Figure 15. The shoreline was filled of floating bags after the submerging.

5.3 Offshore laying

December 18-19, 2006:

There was a manoeuvrability issue when the barge was supposed to position itself above the pre-excavated trench. It is possible that one of the barge thrusters had been damaged during the pull-in, while positioned on the sandbar. It was still able to manoeuvre itself into position as the other thrusters were still operational.

The first few kilometers of cable laying went as planned, and the cable was positioned in the trench. However, the second barge thruster hit something, possibly another sandbar or the excavated material. This second loss of a thruster made the barge unmanoeuvrable. The barge was escorted to the transformer platform with the help of the T/B Nautilus Mammut, leaving the cable within 10 meters of the trench. The last approximately 300 meters were laid to the north of the trench, instead of the south, as planned, because it required less of a turn from the barge.

February 10, 2007:

Approximately 5 kilometers of the cable, which was lying within 10 meters of the trench, was reloaded onto the barge, and relaid to its correct position in the trench. During the time of inactivity from December 2006 to February 2007, the trench had partly filled in with mud. Hence, SSE divers had to flush the cable to its right depth in the trench.

July 1, 2007:

Svensk Sjöentreprenad finally laid the remaining 300 meters of cable in the trench at the end of July/ beginning of August 2007 after the transformer platform had been installed.

6 INTER-ARRAY CABLES

6.1 Inspection of C/S Pleijel 6/5-07

At the arrival of the C/S Pleijel, the draught in bow and stern were measured to read 3.0 and 3.4 meters. The inspection on board included:

- Cable path
- Engine room
- Operating system
- Navigation system

Everything on board looked suitable upon visual inspection of the engine room. The engineer carried out routine tests on a continuous basis.

The operating system consisted of the main engine in the stern, two thrusters on the starboard side and two thrusters on the port side (bow and stern thrusters). The compass thrusters were not utilised due to the shallowness of the water in Lillgrund.

Due to the importance of exact navigation C/S Pleijel was equipped with DGPS and dynamic positioning system (DP). The accuracy of the DP is nearly 1-2 cm in normal conditions. Before every cable laying operation, the crew positions a profiler in the bow. The profiler films the trench that is displayed on the bridge. The monitor verifies the real position of the trench from which the DP can be coordinated.

6.1.1 Cable path

C/S Pleijel was loaded with the inter-array cables in the form of two coils at ground deck. The stern of the ground deck was equipped with a turntable. The turntable was necessary because the bridge above covered half of the coil, figure 16. The deck above the coils (shelter deck) had a hatch cover that remained open during installation.

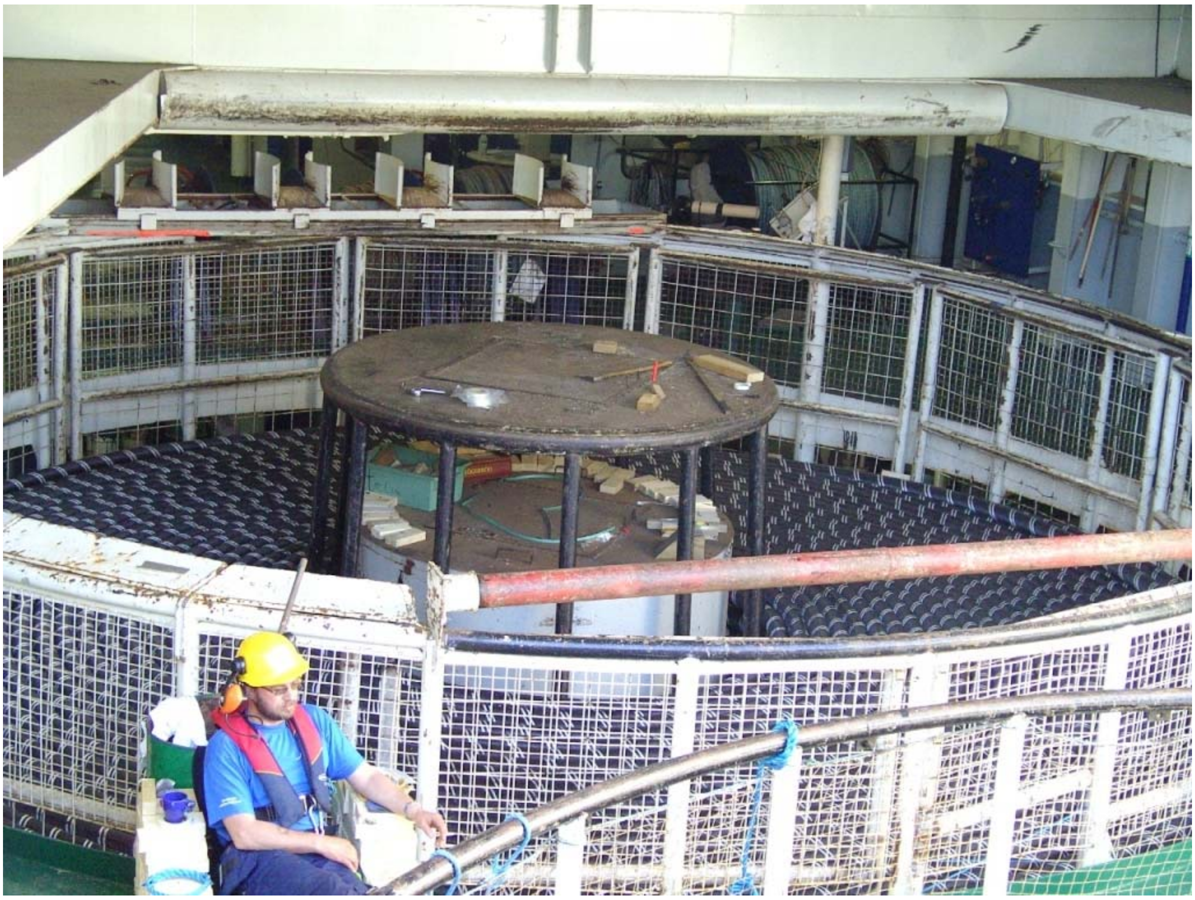

Figure 16. The stern coil was equipped with a turntable.

From the cable coils the cables were pulled up through the gooseneck with a wire, see figure 17. The gooseneck is located on the shelter deck and is articulated to avoid kinks on the cable. Depending from which coil the cable was pulled the angle of the gooseneck is adjusted. It was important to ensure that the cable did not get any kinks when being pulled up.

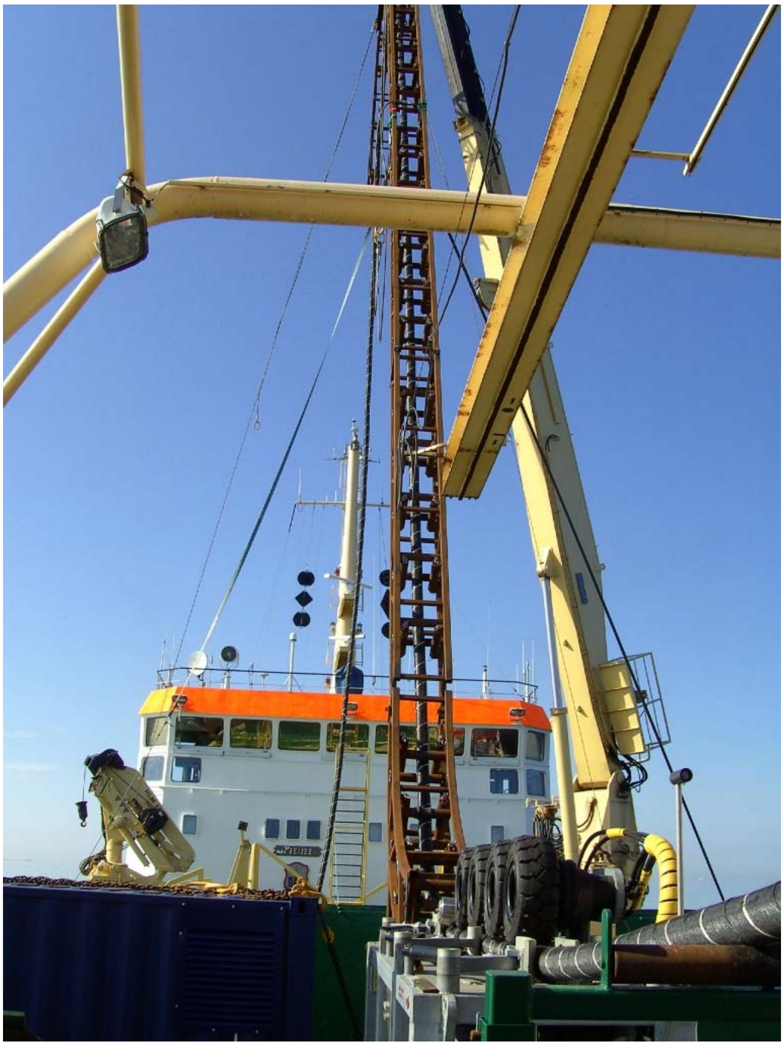

Figure 17. The gooseneck above the coils on the shelter deck.

After the gooseneck came, the linear cable engine would transport the cable into the water by the bow wheel or, under poor conditions, back to the coils, figure 18.

Figure 18. The linear cable engine transports the cable forward to the bow wheel.

The bow wheel operator controlled the speed of the cable engine, figure 19. The bow wheel operator was positioned in the bow where he had a good overview of the cable laying.

Figure 19. The bow wheel operator leads the operation at the bow wheel.

6.2 Installation of the first three inter-array cables

This chapter describes the procedure and the difficulties experienced during the installation of the first three inter-array cables. Most of the mistakes were corrected after these three installations.

6.2.1 First cable G02-H02 May 11, 2007

The first cable was laid between the G02 and the H02 foundations. C/S Pleijel had problems with the navigation system the morning of the installation, possibly due to the following explanations:

- The conditions are often worse at dawn or sunset when there are a lot of reflections
- The weather was cloudy and rainy
- There was a NATO exercise in Östersjön

Another difficulty was that the linear cable engine did not manage to hold the cable in place. Steel plates were installed so the cable could not move laterally.

To be sure it worked, the profiler, which was installed in the bow, ran a sound of the bottom. The lead line and the results from the profiler should correlate. Figure 20 shows the profiler assembled on a steel tube.

Figure 20. The profiler seen is attached to a steel tube, and is fastened at the bow, one meter below sea level.

Figure 21, below, presents the plot of the seabed as shown by the profiler.

Figure 21. Plot of the profile above the trench. The blue is the surface of the seabed and the red circles every second meter from the profiler in the centre. The profiler is not directly over the trench.

During the post-lay survey, M/S Peter Madsen followed a distance too short behind the diver with the umbilical hanging off of the stern end of the boat. The umbilical should have been hanging off the front, far from the engine, to reduce the risk of damage.

M/S Peter Madsen was without a driver for the while that the crew were going for the loose cable end in their workboat. The cook steward was the only one left on M/S Peter Madsen, and it would have been better if the captain or the star man would have stayed on the ship at all times.

During the time the cables were positioned on the floaters, operators had to be aware that the ocean currents could have moved in a direction, which could have caused a kink in the cable during the pull-in, figure 22.

Figure 22. The water current affected position of the cable and the floaters during the pull-in.

6.2.2 Cable G02-F02 May 12, 2007

During the second cable laying between G02 and F02 the weather conditions were good. C/S Pleijel did not have any significant difficulties; the team just needed to do the work a couple of times to get into a routine.

This time, during the post-lay survey of the cable, M/S Peter Madsen followed the diver at a larger distance and with the umbilical hanging off the front of the boat.

The communication between C/S Pleijel and M/S Peter Madsen could have been better. It was frustrating for all involved when one party did not know what the other was doing.

6.2.3 Cable F02-E02 May 13, 2007

Communication problems were apparent when M/S Peter Madsen went to the wrong foundation to install this segment of cable. This was corrected, and work to improve the communication between the teams has continued since.

6.3 General comments on the inter-array cable installations

6.3.1 J-Tube Caps

In every foundation there was a j-tube from the seabed to the top of the foundation, which was designed for the cable. One meter below the seabed, a bell-mouth with an enclosure cap, was mounted on the j-tube. The enclosure cap had to be removed before the cable pull-in, figure 23. Mud had filled in outside of the enclosure cap, requiring divers to vacuum the space before every pull-in so the cap could be removed. Because of the water current direction, clearing the space in front of the caps took 15 - 30 minutes each on the south sides of the foundations and up to two hours on the north sides of the foundations.

Figure 23. The enclosure cap removed from the bell mouth.

6.3.2 Inter-array cable pull-in

At each foundation location, C/S Pleijel began the operation by pulling the cable through the j-tube of the foundation, first, feeding the cable from the bell-mouth underwater up through the shaft and out of the foundation top. The other end of the cable was floated towards the second foundation, until it got within 30 - 40 meters from it, before the cable was pulled through that second foundation, figure 24.

Figure 24. Cable floating from C/S Pleijel, M/S Peter Madsen in the background.

Due to water current pulling the cable there was sometimes a risk that the cable would get a kink. During those risky pull-in operations the workboat pulled the cable to minimise this risk, figure 25.

Figure 25. A workboat pulled the cable to minimise the risk for a kink

6.3.3 On the foundations

To ensure that enough cable was provided to each foundation, the cable was pulled 6 - 8 meters above the j-tube top. The cable armour was removed for this length before the cable was secured, see figure 26 below.

Figure 26. The cable armour was removed with help of an angle grinder

At every foundation where the cable laying was ending there was more cable than necessary. This extra length of cable was cut off using a tiger saw, figure 27.

Figure 27. A tiger saw was used to cut the excess length of cable

7 COMMENTS AND CONCLUSIONS

The cable installation process was complex and an important step for Vattenfall AB, considering the limited experiences previous to Lillgrund of building offshore wind farms.

7.1 Weather dependent operation

The cable installation is very dependant on weather conditions. The longer time the installation is predicted to take, the more important is it to choose the right season. In Lillgrund, for example, the export cable was scheduled to be installed in October but first attempts were postponed until December due to poor weather conditions.

In conclusion, it is recommended to schedule the cable installation work during statistically good weather seasons, attempting to avoid winter by a comfortable margin.

7.2 Method

The method of excavating the trenches first and then coming back to lay the cable weeks later worked well for the installation of the inter-array cables. However, the export cable was only installed correctly after many setbacks.

Sweden and Denmark do not share the same diving regulations. Sweden allows diving from a moving ship and Denmark requires the ship to have its spuds down and the engines turned off. This was confusing for the Danish crew in the beginning of the installations.

In Lillgrund, the seabed soil profile consisted of mainly very stiff bolder clay. The clay was advantageous for excavation because of its stiffness and allowed the trench to have almost vertical walls. It also allowed the excavated material to remain close to the trench during the backfilling. In the few areas where the seabed was not as stiff, a pre-lay excavation was necessary.

Another advantage of the stiff bolder clay was that very few particles of the material followed the water currents during the excavation. In areas with soft seabed material, and at areas with a depth less than 3 - 5 meters, seabed material was clouding the water by the thrusters on the cable ship.

7.3 Environmental impact of the installation operation

The environment is affected by the installation both during the excavation and during the cable laying. During the excavation, small particles from the clay followed the water currents and, depending on how strong the current was, the particle cloud could be hundreds of meters in length. A supervisor for the authorities notified the operators that this was a problem early in the excavation, and was quickly addressed by limiting the height of the bucket over the seabed.

During the cable laying, when the trench was completed, the impact on the environment was considerably lower. The clay particles normally settled very quickly, often within less than an hour.

A minimum of one meter of installation depth was required, but was not met in some locations. Close to the shore, some rocks were found in the trench while the cable was being water jetted. The installation at a depth of half a meter was approved in these cases because blasting would be a much worse alternative from an environmental point of view. At trench sections where the depth was less than half a meter, the trench had to be covered by rocks.

8 REFERENCES

[1] Ljung, P. Method description Array cable installation for Lillgrund. February 21, 2007

[2] Madsen, M. Conversation during the first inter-array cable laying. May 11, 2007