

Experiences from the Construction and Installation of Lillgrund Wind Farm

Lillgrund Pilot Project

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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

Information in this report may be used under the conditions that the following reference is used: "This information was obtained from the Lillgrund Wind Farm, owned and operated by Vattenfall."

The views and judgment expressed in this report are those of the author(s) and do not necessarily reflect those of the Swedish Energy Agency or of Vattenfall.

Experiences from the construction and installation of Lillgrund wind farm

SUMMARY

The conditions for establishing an offshore wind farm at Lillgrund, the southern, shallow part of Öresund, are very favourable. Good wind speeds result in a high energy production, the proximity to the shore means relatively easy access for construction and maintenance and a short export cable. With the water depth being only four to twelve meters, the cost of the foundations is controlled.

The Lillgrund offshore wind farm is comprised of 48 offshore 2,3 MW wind turbines and a transformer platform, resulting in a total rated production of 110 MW. The construction work on the site was carried out from March 2006 to December 2007.

What makes offshore construction special is, apart from the marine environment, its dependence on weather conditions. All activities at the wind farm requires a suitable "weather window" to allow the work to be carried out safely.

The project has been financially supported by the Swedish Energy Agency ("Energimyndigheten").

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1 INTRODUCTION

The conditions for establishing an offshore wind farm at Lillgrund, the southern, shallow part of Öresund, are very favourable. Good wind speeds result in a high-energy production, the proximity to the shore means relatively easy access for construction and maintenance and a short export cable. With the water depth being four to twelve meters only, the cost of the foundations is controlled. Transportation of material is easily facilitated in this area and is required as foundations and wind turbines are shipped directly to the site at Lillgrund.

2 BACKGROUND

In the autumn of 2004 Vattenfall purchased the rights to the project from Eurowind, who had started the permit process in 1997. All permits were received in 2005. A later application to allow the increase of the total hub height from 105 meters to 115 meters has not yet received a final approval from the authorities.

The Lillgrund offshore wind farm is comprised of 48 offshore 2.3 MW wind turbines and a transformer platform, resulting in a total rated production of 110 MW.

The wind power stations consist of gravity base foundations and wind turbines. The three main components that comprise the wind turbines are a tower of 70 meters height weighing 134 tons, an 82-ton nacelle and a 60-ton rotor with three blades. An offshore high-voltage transformer station was built just north of the wind farm and a submarine 138 kV export cable connects the wind farm to the Swedish grid. Dredging work had to be carried out prior to the foundations being placed on the seabed. All cables were buried one meter into the seabed.

A number of environmental studies and control programs have been carried out: flora and fauna, fishing and fishery, birds, sedimentation during dredging works and noise.

The project has been economically supported by the Swedish Energy Agency ("Energimyndigheten").

3 PROCUREMENT

Proven technology is essential as the location of the offshore wind farm is subject to high maintenance costs. Two contracts were used to purchase the facilities: one for the foundations and one for the wind turbines including all cabling.

The project team acquired additional services and equipment, such as a site office, an inspection vessel and a work vessel coordinator.

Vattenfall Insurance was responsible for procuring the All Risk Construction Insurance for the entire project. It included coverage for all contractors, sub-contractors and professional consultants.

3.1 Foundations

After a pre-qualification round, a number of contractors were invited to bid for the wind foundation contract. This included bidding for the construction, transportation to Lillgrund

and the installation, as well as the seabed preparations. The contractors were free to bid for both gravity and monopile foundations.

For the technical evaluation the following 13 main issues had been identified:

- Form of cooperation
- Organisation plan
- Subcontractors
- Design documentation
- Fabrication of the foundations
- Seabed preparations
- Installation of the foundations
- Permits and conditions
- Program
- Planning
- Extended warranty
- Options
- Qualifications

The evaluation arrived at the result that a consortium of the two construction companies Pihl & Son and Hochtief, Pihl-Hochtief Joint Venture, had put forth the most favourable bid for a gravity based foundation, made of reinforced concrete.

3.2 Wind turbines

After a pre-qualification round, a number of contractors were invited to bid for the wind turbine contract including all of the cabling work.

The most favourable contractor was selected based on the following criteria:

- Profitability
- Proven technology
- Previous experience
- Interface information
- Aesthetic information
- Environment and noise

The evaluation concluded that Siemens Wind Power A/S had put forth the most favourable bid for a 2,3 MW MkII wind turbine, which was accepted.

4 IMPLEMENTATION PERIOD

The first activity to take place on the site at Lillgrund was to mark the work area with navigation marks. The Länsstyrelsen in Skåne decided that this was to be a restricted area during the construction time. This meant that vessels needed Vattenfall's permission to gain access to the area inside the navigation marks. All other vessels could be stopped from entering the area. We cooperated with the Swedish Coast Guard and could rely on their assistance for the removal of unapproved vessels.

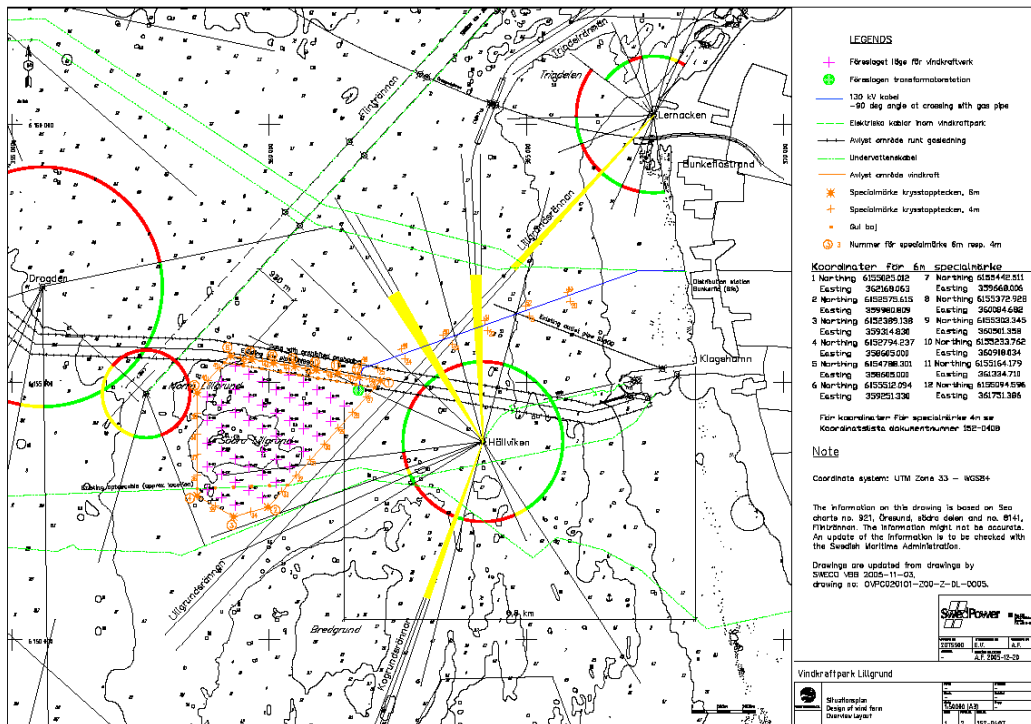


Figure 1: Restricted area at Lillgrund

Main events during the construction period:

- The local site office in Klagshamn was built in April 2006.
- The construction work for the foundations started early in 2006.
- The precast concrete foundations were transported on barges directly from the Polish manufacturing plant in Swinoujscie and delivered on site, starting in June 2006 with the last foundation delivered in February 2007.
- The export cable, from the transformer platform to shore, was laid in the winter of 2006/2007. All sea-cables were buried in a one-meter deep trench, which had been dug out by hydraulic excavators. After the cables were laid, the trenches were refilled with the excavated material.
- The transformer platform was installed in June 2007.
- The inter array cables, between the wind turbines, were laid in the summer of 2007.
- The first wind turbines were connected to the grid in October 2007 and in November all 48 wind turbines were supplying electricity to the public grid. The test operation was completed in December 2007.

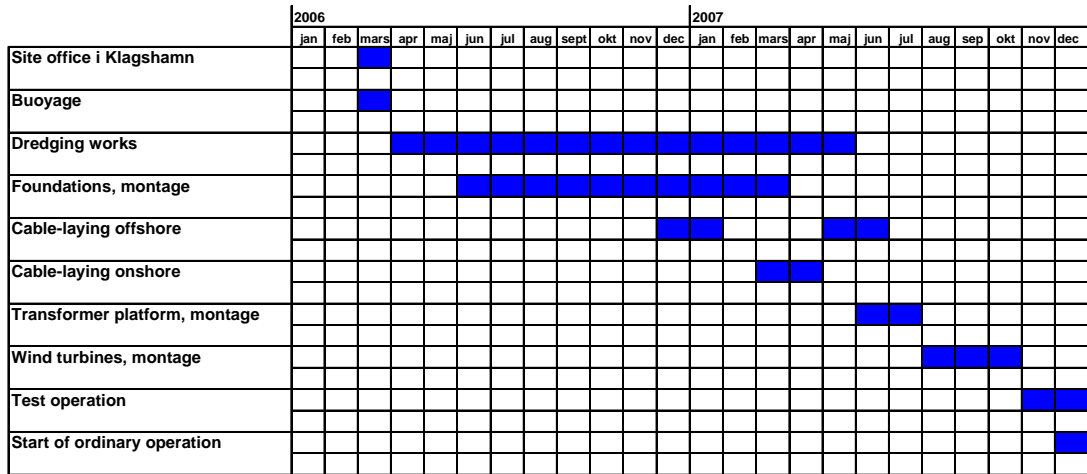


Figure 2: Main time schedule

5 PROJECT ORGANISATION

The organisation and staffing evolved during the life of the project due to the change in priorities tailored to the phase of the project. In the early phases of the project, procurement had an important role, in the later phases offshore activities became more important.

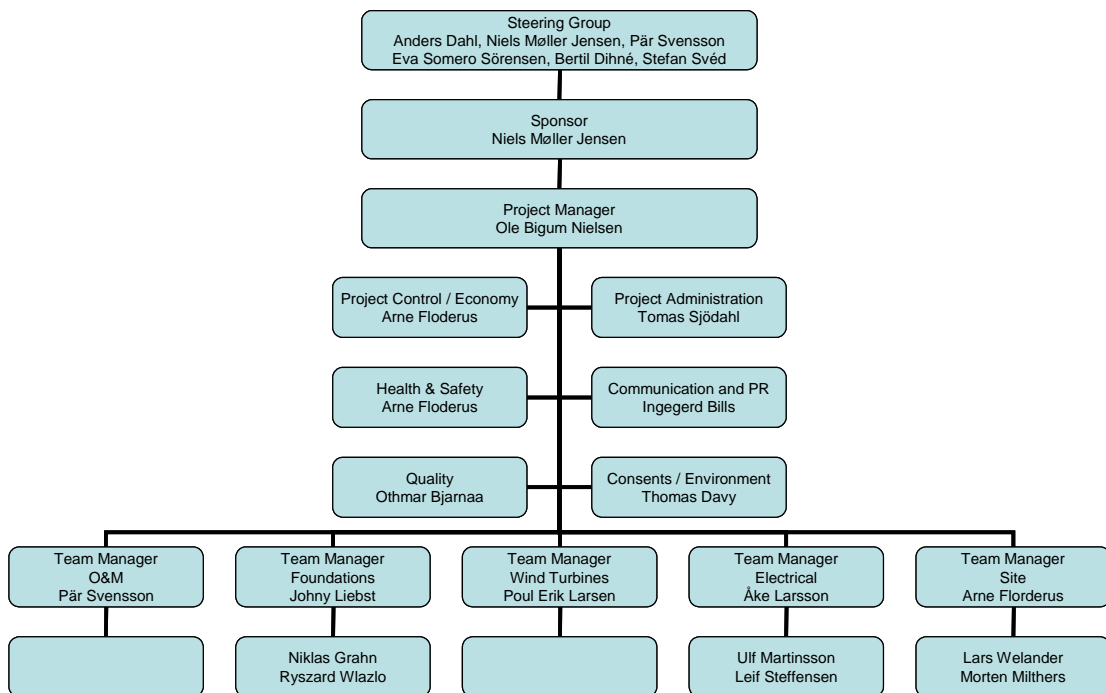


Figure 3: Project organisation chart for the later project phases

6 WEATHER

What makes offshore construction special, apart from working in the marine environment, is its dependence on weather conditions. All activities at the wind farm require a suitable “weather window” to allow the work to be carried out safely. Special consideration has to be made in respect of the weather window for all operations such as the transport of barges from Poland to Sweden, crane lift operations and cable laying.

A daily weather log has to be kept to make it possible to identify the weather conditions at any given time. This log plays a major role in negotiations with contractors regarding their claims for compensation due to bad weather.

7 WORKING ENVIRONMENT

The offshore industry has traditionally paid great attention to ensuring maximum safety in all operational conditions. The same stringent rules, such as those for vessel boarding and disembarking, also apply in the offshore wind industry.

Both workers and visitors alike have to follow the work vessel coordination procedures.

The work vessel coordination office at Klagshamn also acts as the coordination centre in case of emergency anywhere in the project.

The wind farm at Lillgrund poses a potential hazard to shipping. The wind farm is located outside of designated traffic channels, but in the event of a ship losing its manoeuvrability capabilities, there is a risk of collision with a wind turbine. Large ships without navigation control, coming from the west or the south, will run aground before they reach the wind farm. Even prior to the installation of the wind farm, sea charts covering the area showed the location of the wind farm, thus warning ships against passage, and therefore, getting them accustomed to avoiding that area. According to a risk assessment study by COWI, the possibility of ship impact on one or more wind turbines is one in every 6,000 years. The largest environmental danger during a ship collision is the risk of oil leakage from ships and wind turbines, but these wind turbines contain their oil in sealed systems, reducing the risk of oil-spills from a collision or operational activities.

During the construction period all foundations were fitted with a small, solar-powered flashlight showing the position of the wind farm during the night.

7.1 Authorities

An Emergency Alarm Plan (Larmplan + Insatsplan) was issued in cooperation with the following authorities:

- Rescue Service in Malmö City (Räddningstjänsten)
- Medical Service of Malmö City (Region Skåne)
- The Coast Guard (Kustbevakningen)
- The Navy (Marinen)
- SOS Alarm
- Sea Rescue Service (Sjöräddningen)
- MRCC (Sjöfartsverkets sjöräddningscentral i Göteborg)

7.2 Work vessel coordination

The purpose of the work vessel coordination is:

- To coordinate all project related sea traffic at the wind farm as well as sea traffic to and from the construction site.
- To provide all personnel working offshore with a Lillgrund Wind Farm ID card, thus enabling the work vessel coordinator to keep track of personnel and vessels.

The work vessel coordination office was located at the Klagshamn harbour site office.

The following equipment was available for communication between the work vessel coordination office and the vessels at Lillgrund:

- Mobile phone.
- Marine VHF with P-channel, stationary and portable. (P-channel is an assigned wavelength for a specified purpose only)
- Internet access (ADSL) with E-mail.
- AIS (Automatic identification system, showing the positions of the vessels on a screen).

All vessels within the work vessel coordinators' area of responsibility were required to have a VHF radio with an additional P-channel. In order to ensure immediate contact between the vessels, audio surveillance on the P-channel was required at all times.

Prior to entering the work area all vessels were inspected by the work vessel coordinator or an appointed marine superintendent. Work vessel coordination meetings were held on a weekly basis, to plan and monitor the safety work on site.

7.3 Work vessel coordination procedure

The work vessel procedure work includes:

- Organising a monitoring system for vessels and personnel.
- Keeping a database for all vessels and personnel.
- Handling NOK forms.
- Issuing ID cards to personnel with the relevant courses and certificates.
- Keeping a log of the positions of the working vessels.
- Management of the maintenance of buoy measuring equipment.
- Organising transport of construction project personnel to the work site.

To receive an ID card and to be allowed to enter the work area the following was required:

- NOK forms.
- Sea safety course.
- Tower climbing course + First aid course for personnel working above the concrete platform of the wind turbines.
- Exceptions can be made for "one day visitors" and persons not disembarking from a vessel.

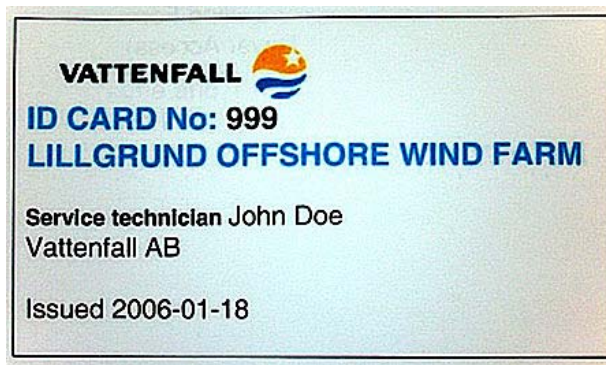


Figure 4: Example of ID card

For high-risk operations, such as transfers during night time, special procedures are implemented. The following equipment has to be available during night transfers: Crewfinder (radio beacon EPIRB), light beacon and light sticks in the life jackets.

All vessel movements and the identification numbers of personnel onboard and all transfers of personnel have to be logged by the vessel and transmitted to the work vessel coordinator.

7.4 Weather forecast

It is of great importance to all offshore work to get proper forecasts of the local weather and wind conditions. For diving operations the water current forecast is of great use, since maximum permitted water current for working in the water is one knot.

Offshore operations in elevated positions have to be suspended in bad weather. Some offshore activities require a long weather window. If on-site conditions are deemed unsuitable for operations, vessels have to return to a sheltered harbour or bay and wait for the weather to improve.

8 FOUNDATIONS

The foundations are gravity base foundations of reinforced concrete. The total combined weight of the foundation and the wind turbine provides the necessary stability to the complete wind turbine unit.

The Pihl-Hochtief consortium rented a part of the harbour in Swinoujście, Poland, to manufacture the foundations. A ready-mix concrete plant was installed very close to the quay to facilitate concrete production, pouring and transport.

8.1 Dredging, preparatory work

The seabed was dredged until the required excavated profile was achieved and sufficient bearing capacity of the seabed obtained. The excavation work was finalized by a diver inspection and cone tests to indicate the status of the seabed. The excavated area was

filled with a 50 cm thick cushion layer of crushed stones, to form a horizontal base for the foundations. Before the foundations were placed on the cushion layer, it was inspected by divers to ensure that no debris had entered the area.

Careful operation prevented spillage from exceeding 5 % of the excavated volume, being the maximum spillage permitted by the authorities.

8.2 Manufacturing

To simplify the manufacturing and transport to Lillgrund, the foundations were constructed as prefabricated concrete foundations, made directly on large barges, which were moored in the harbour of Swinoujscie. Four foundations were cast on each individual barge. As the bolt tolerances were very tight, the bolts were placed in fixing plates before the concrete was poured into the shutter boarding.

The different water depths at Lillgrund made it necessary to build the foundations in five different standard heights. The average onshore weight of a foundation is approximately 1500 tonnes. With 500 tons of ballast material on the base plate, the total weight is approximately 2000 tons.

8.3 Transport to site

When the concrete for all four foundations had burned the required time and the work on the barge was completed, a tug pulled the barge from the harbour of Swinoujscie to Lillgrund. This operation required a weather window of more than 24 hours.



Figure 5: A tug takes the barge with four foundations from Poland to Lillgrund

8.4 Installation

The crane barge was manoeuvred close to the foundation barge, where the cradle was fitted below the ice cone to lift the foundation clear of the barge. The crane barge was then moved to a pre-programmed location and the foundation was lowered on to the seabed. Once the foundation had been set in position on the seabed, open cavities around the foundation were filled with a special heavy stone material from Norway for additional stability.

The position of each individual foundation within the wind farm was mapped precisely, and the crane barge was pulled to each new location with the aid of a tug and anchors. Precise positioning was achieved with the aid of a four-anchor system and a global positioning system (GPS).

The whole area of the seabed around the foundation was covered with a rock-fill scour protection to prevent the ocean currents from moving seabed material and thus undermining the stability of the foundation.



Figure 6: The crane places the foundation in its exact position

9 WIND TURBINES

9.1 Manufacturing

The manufacturer, Siemens, have manufactured the nacelles and blades in their own factories in Jutland, Denmark. Two sub-suppliers, also located in Jutland, made the towers. All equipment was transported by lorries from the factories in Jutland to the assembly place and shipping port of Nyborg on Fyn.

9.2 Assembly site

A few days before the towers were taken out to sea, they were placed upright for final assembly work. Three blades, forming the rotor, were fitted to the hub. The towers (upper and lower sections), the nacelles and the rotors were loaded onto a special ship by a large crane. This ship, the Sea Power, had enough space for the components of three complete wind turbines.



Figure 6: Loading the wind turbines in the harbour

9.3 Transport to site

The total average time for installing the load of three wind turbines took five days: One day for the journey from Nyborg to Lillgrund, two days to erect three wind turbines, one day for the return journey to Nyborg and finally one day to load three more wind turbines. As long as weather permitted, these activities were carried out 24 hours a day, seven days a week.



Figure 7: The Sea Power leaves the Harbour of Nyborg

9.4 Installation

When the Sea Power reached its destination at Lillgrund, it was positioned 15 meters from a foundation. The vessel raised itself two meters by means of four jack-up legs to stabilize the hull for waves, and then the installation of the wind turbines could be carried out. The elevated deck of the Sea Power offered a safe and stable work platform. A mobile gangway was extended out to the foundation to provide easy access for the fitters.

The large crane was taken into operation and started lifting the lower part of the tower, then the upper part of the tower followed by the nacelle, and finally the rotor, into position. Once the parts were in place the different components were bolted together. The Sea Power is capable of operating in marine conditions with wave heights of up to one meter. Installation of towers and nacelles can be carried out in a wind speed of up to 10 m/s whilst installation of rotors is limited to a wind speed of maximum 7 m/s.



Figure 8: Wind turbine installation

10 TRANSFORMER STATION

10.1 Manufacturing

The steel framework of the transformer platform was made in Poland. It was transported to Århus, Denmark, where all electrical equipment was installed, along with the internal and external walls. All paintwork was also carried out in Denmark.

10.2 Transport to site

The completed transformer station was transported on a barge to the Copenhagen harbour, where a marine crane lifted it directly to its planned location at Lillgrund.



Figure 9: The transformer station was placed on a transition piece of the foundation

11 CABLE LAYING

Experiences from the cable laying work are described in a separate report.