

EXPERIENCE FROM THE ESTABLISHMENT OF MIDDELGRUNDEN 40 MW OFFSHORE WIND FARM

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ABSTRACT: The paper describes the special issues, which differentiate the offshore wind farm from an onshore wind farm of the same size. The paper is based on the experience gained during the establishment of the Worlds largest offshore wind farm Middelgrunden, 40 MW established 3.5 km outside Copenhagen harbor in the autumn of 2000. The paper concludes based on the experience gained and draws the line to the coming wind farms with a power of total 750 to 780 MW in Danish water: Horns Rev, Rødsand, Samsø, Omø Stålsgrunde and Læsø.
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1 INTRODUCTION

The Middelgrunden Wind Farm has a rated power of 40 MW and consists of 20 turbines, each 2 MW. The farm was established during year 2000 and is the world's largest offshore wind farm. The farm is owned partly by the Copenhagen Utility and partly by a cooperative with 8,552 members. The farm delivers more than 3% of the electricity used in Copenhagen (see table I and II).

The wind farm is situated on a natural reef 3.5 km east of the Copenhagen harbor. The reef has for more than 200 years been used as dumpsite for harbor sludge and other contaminated waste. Special environmental impact studies and feasibility studies have therefore been carried out [1], [2], [3], [4] and [5].

An old dry dock of a former shipyard was used for casting the concrete gravity foundation. The foundation together with the lower section of the turbine tower including transformer and switchgear was floated out to the site in the autumn of 2000. The abandoned shipyard was also used for assembling the rotor, which, together with the upper section of the tower and the nacelle, was floated out on a barge. For positioning of the turbine a jack-up platform was used (see [6] and [7]).

Table I Facts about the Middelgrunden Wind Farm.

Power	40 MW
Hub height	64 meter
Rotor diameter	76 meter
Total height	102 meter
Foundation depth	4 to 8 meter
Foundation weight (dry)	1,800 tons
Wind speed at 50-m height	7.2 m/s
Guaranteed/expected power output	89/100 GWh/y
Park efficiency	93 %.

Table II Partners involved

Owner 10 turbines north	Copenhagen Energy
Owner 10 turbines south	Middelgrunden Cooperative
Project management	SEAS, Wind Energy Center
	assisted by SPOK ApS (EMU)
Design	Møller & Grønborg
Foundation design	Carl Bro as
Manufacturer of turbines	Bonus Energy A/S
Contractor, foundation including sea work	Monberg & Thorsen A/S & Pihl & Søn A/S
Contractor, submarine cable	NKT Cable A/S
Switchgear and transformer	Siemens A/S



Figure 1: The location of the Middelgrunden Wind Farm east of Copenhagen harbor.

2 THE TIME SCHEDULE

In December 1999 the contracts with the contractors were signed. New rules just introduced for the wholesale price of power from renewable energy resulted in a very narrow timetable for the decisions connected to the start up of the project. The short planning time resulted in extra costs and special precautions not necessary for a future project of the similar kind with more time available for planning, but still within the budget.

The type and size of the turbine itself influenced the design of the support structure, the construction method and the establishment of the connection to the submarine cables. The parallel decision as used in the Middelgrunden project was necessary because of a change in incentives January 1st 2000 and cannot be recommended. The extra costs resulting from the tight timetable resulted in:

- Extra mould for concrete casting.
- A larger floating crane.

- A change in the seabed preparation.
- The final period for sea operations were prolonged several month into the winter season.



Figure 2: The Middelgrunden Wind Farm.

The use of a larger floating crane turned out to give opportunity to revise the way of the total installation in a positive way. The larger capacity allowed the lower tower section including switchgear, transformer and control equipment to be established in the dry dock. The lower section of the tower already placed on the foundation allowed thereafter an effective way of pulling up the submarine cables into the tower as soon as the foundation was placed on its final site.

3 OFFSHORE COMPARED TO ONSHORE WIND FARMS

The main differences to onshore-based wind farms are:

- The preparation of the seabed for the foundation.
- The difficulties getting access to the turbines.
- The establishment of the submarine cables.
- The high voltage equipment situated in the tower.

4 THE SEABED PREPARATION

The seabed preparation showed up as more complicated than expected by the contractor. The deposited harbor sludge around the established excavation for the foundation up to a depth of 5 meters was almost liquid. Large amount of fine particles suspended in water had to be removed from the established foundation level several times before placement of the gravity structure.

The compaction of the rock cushion was much more complicated and time consuming than expected by the contractor. Several sites needed injection after the placement of the foundation in order to secure sufficient contact to the compacted rock cushion.



Figure 3: A safe access to the foundation is essential when the waves and current are moving the ship.

A failure in the calibrating of the pressure gauge combined with a too weak control procedure for standard operations resulted in the fact that more than half of the foundations were placed 20 to 38 cm too high. The acceptance criterion was 10 cm. In August 2001 one of the foundation will be modified in order to fulfill its role as icebreaker.

5 THE INSTALLATION OF FOUNDATION, SUBMARINE CABLES AND TURBINES

5.1 Foundation

The floating of the gravity structure including the lower section of the tower worked out satisfactory. Careful estimation of low tide was necessary, as there at a time was only 10 to 20 cm between the concrete slab and the seabed. The work was carried out day and night depending of the weather forecast. The positioning in horizontal direction was far within the tolerances specified. The vertical inclination of the tower was better than the requested accuracy. The special measures to cope with too high deviations in inclination were not activated.



Figure 4: The floating crane with a foundation and the lower part of the tower at the site just before installation.

5.2 Cables

The establishment of the submarine cables was carried out without any difficulties using a special build vessel from NKT Cables. The relatively shallow water and good weather conditions contributed to that.

The work within the tower separating the marine reinforcement from the core of the stiff cables turned out to be much more complicated than expected because of the narrow space.

The contractors working with the establishment of erosion protection damaged the cables three times, even though it was a simple sea operations of a well-proven type.

5.3 Turbines

The use of a jack-up for placing the upper tower section, the nacelle and the rotor was necessary in order to secure a solid work platform for the 80-meter crane [7].

The work turned out to proceed much faster than feared. A record of 18 hours for completing two turbines was obtained.

6 THE OPERATIONS AT SEA

6.1 Divers

The bottleneck of the project was for a long period the access to divers. Almost all divers available from the eastern part of Denmark were activated during the peak period working with:

- Placing of cables and pull-up of cables in the tower
- Digging for the foundation and cable trench
- Placement and compaction of rock cushion
- Leveling of compacted rock cushion
- Placement of foundation caisson
- Removal of block for lifting operations

6.2 Final establishment of power connection

The final check of switchgears and grid connection turned out to be more time consuming than anticipated. One reason can be the successive starting up of the turbines, which called for several 24 hours periods of test for grid and power stability.

The successive starting up also gave unexpected problems, as the power backup for starting up the switch gears was not foreseen to be larger than during normal operations.

6.3 Planning

Carefully planning day-by-day was necessary in order to avoid that seabed operations upstream resulted in impossible working conditions downstream caused by particles in the water. Also the weather situation had to be taken into account.

After installation of the turbines up to 38 people coming from different companies were working every day on the different turbines. People were often shifting between turbines during the day. To secure the best and most safe working conditions, two persons were dedicated only to coordinate these tasks.

7 THE TIME SCHEDULE

The first turbine started production at the end of December 2000 and the last at March 6, 2001. The total delay compared to the original timetable was 2 to 3 months. The reason for the delay was:

- More difficult seabed preparation than expected by the contractor especially the compaction of the rock cushion
- 3 accidents with damages of the submarine sea cable
- Delay caused by the weather condition as the building period was prolonged to the winter season
- Longer time for the work at the turbines with the final connection to the grid than expected.

If the lower section of the tower had not been established in the dry dock, a much larger delay would have appeared.



Figure 5: The switchgear and transformer on top of the concrete foundation ready for placement of the tower.

8 ECONOMY OF THE ESTABLISHMENT

The budget for the establishment is given in table III. During the onshore part of the building period it was expected that the expenses would have been 10% lower. During the establishment, unforeseen expenses appeared mainly caused by the condensed planning and construction period, as mentioned in section 2. The result has been that the budget given in table III is the true picture of the final costs.

Table III Budget of the wind farm, grid connection from land to the farm not included [8]

The total investment in the project	EUR (mill)
Wind turbines	26.1
Foundations including changes after the tender to reduce the time on sea	9.9
Grid connection, off-shore	4.56
Design, advice and planning	2.15
Wind turbine cooperative	0.54
Other costs	1.61
Total	44.9

9 THE PRODUCTION THE FIRST ½ YEAR

The total power produced after six month of production is 29.8 GWh. The farm has not been producing regularly during all 6 months as many small corrections have been carried out. First from mid June there have been no planned interruptions. The production yield can be judged in the following way:

- The power curve shows 5,7% better performance than guaranteed (see figure 6).
- The power produced compared with the expected value of eastern Denmark is about 20% higher. This is following the tendency known from the Lynetten Wind Farm situated at the Copenhagen harbor.
- The shadow effect is as expected considerable with wind directly from north or south.

Table IV Sales price of electricity delivered to the grid from the Middelgrunden Wind Farm

Year	Fixed price	Added price for renewable energy
	EUR/kWh	EUR/kWh
0-6	0.044	0.036
6-10	0.044	0.013 to 0.036
10-25	Market price	Green label certificate to be traded

Table V Key figures for production based on budget, interest rate 5% and 25 years lifetime, [8] and [9]

Production price of electricity	0.046 EUR/kWh
of which service	0.009 EUR/kWh
Investment/kW	1.14 EUR/kW
Production (guaranteed)	89 GWh/y

Production figures can be found on the Internet: www.middelgrund.com. The information is updated every 10 minutes.

Unfortunately the EU FP5 has not supported a planned comprehensive measuring program enabling to explain the influence from e.g. turbulence and shadow effect from the turbines placed only with a distance of 2.4 times the rotor diameter. Today the Danish Energy Agency and SEAS support a minor test program.

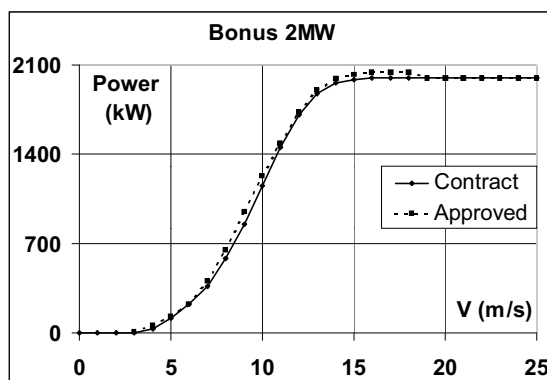


Figure 6: Power curve for the 2 MW turbines based on approved measurements [5].

The recommendations for new offshore wind farms in Danish waters [10] are:

- The turbine tender has to be conducted before the foundation in order to avoid changes in the detailing if possible
- Special development is needed for placing and compaction of the rock cushion
- All operations have to be tested in advance - also the ones looking simple, as all operations of the standard type onshore are complicated offshore
- Carry out as many operations onshore as possible
- Transport of people to the turbines offshore has to be organized very carefully
- Logistic planning is a must for keeping the time schedule
- Onshore 690 V experience can not be transferred to cables at 30 kV, as special safety is required
- Successive starting up of the production seems easy, but gives problems of many kinds
- Moist in the turbine tower was higher than expected before turbines came into operation.

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10 LESSONS LEARNED