Nissum Bredning - Technical Report for 28 MW Pilot Project

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Contents

1. Introduction ... 3

2. Element #1 - 0- series test of SWP SWT-7.0-154 WTGs ... 4

3. Element #2 - Prototype type test of SWP Gravity Foundation ... 5

3.1 Current Status of Support Structure ... 6
3.2 Geotechnical investigations ... 6
3.3 Ice Loads ... 7
3.4 Concrete Transition Piece (TP) ... 8
3.5 Logistics and Installation ... 9

4. Element #3 - Prototype of Slender Tower Concept (5.5m) ... 10

5. Element #4 - Prototype test cables in Pipes (CIP) ... 11

5.1 Main components concept ... 11
5.2 Geometry and Elevations ... 11
5.3 Installation ... 13

6. Element #5 - 66 (72kV) kV cables and switchgear solution ... 15

7. Element #6 - Test of LIDAR power curve measurement ... 15

8. Element #7 - Synchronization of rotors - Visual appearance ... 15

9. Element #8 - Optimized use of sensors and limitation of loads through reduced output from the WTG ... 15

10. Overall Time line ... 16

1. Introduction

Based on Energistyrelsen's (ENS's) invitation to apply for test arrangements for new offshore technology (INDKALDELSE AF ANSØGNINGER TIL FORSØGSORDNING FOR NY HAVVINDTEKNOLOGI) issue on 14th July 2015, Jysk Energi AMBA, Nissum Brednings Vindmøllelaug I/S and Siemens Wind Power A/S forwarded their application on 2015-10-15. February 10th 2016 Energistyrelsen announced the 28 MW "Nissum Bredning - Testbed for new technology and integrated design" project as winner of the competition.

The final approval was issued to I/S Nissum Bredning Vind (55% owned by Nissum Brednings Vindmøllerlaug I/S (app. 2000 local persons) and 45% Jysk Energi A/S and will be built as a Turn-key project by Siemens Wind Power A/S in accordance with the Danish legal requirements and 8 development, demonstration and test elements:

1) 0-series test of SWP-7.0-154 WTGs
2) Prototype type test of SWP Gravity Foundation
3) Prototype of Slender Tower Concept
4) Prototype test of cables in Pipe (CIP)
5) 66kV (72kV) cables and switchgear solution
6) Test of LIDAR power curve measurement
7) Synchronization of rotors - Visual appearance
8) Optimized use of sensors and limitation of loads through reduced output from the WTG.

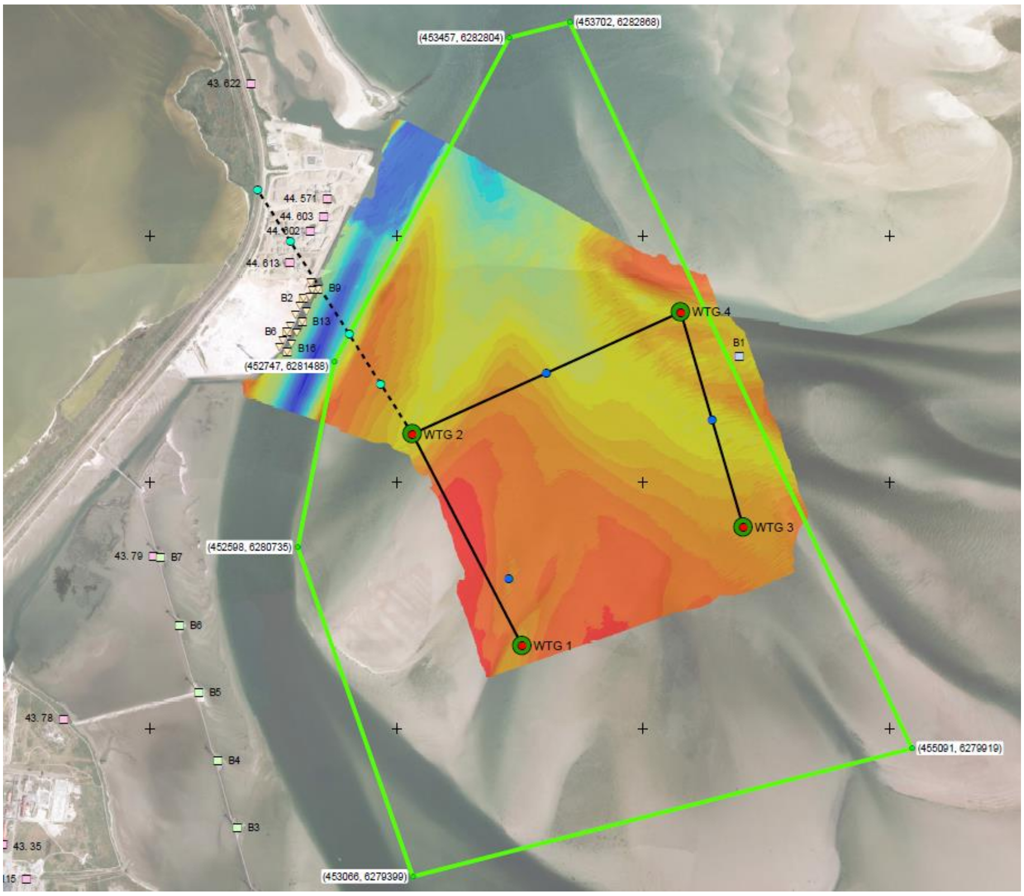
The project will be Project Certified according to Danish requirements. DNV GL is selected as project certifier. The D7 type certificate for the Rotor Nacelle Assembling (RNA), so called A-Type certification, is obtained for the 33kV version and will form an integrated part of the Project Certification. The upgrade to 72kV covering the Transformer and 72kV cable system in the turbine will be available prior to energization. Structural design certification is ongoing.

DNV GL has been select as Marine Warranty Surveyor and is approved by the project insurance companies.

The Turbine will be located:

WGT1 - 453510.00, 6280335.00
WGT2 - 453064.00, 6281196.00
WGT3 - 454407.00, 6280817.00
WGT4 - 454153.00, 6281691.00

UTM WGS84 Zone 32



This first technical report will describe the technical elements together with an overall time line.

2. Element #1 - 0- series test of SWP SWT-7.0-154 WTGs

7.0MW is a focused update of the 6.0MW platform where the emphasis was on minimum design changes and risk, reuse of the same supplier setup, assembly operations and installation processes and can deliver about 10% more energy than the 6.0MW, and thus reduce the cost of energy.
The focused design changes to the 7.0MW WTG contain the following:

Improved Direct Drive Generator with greater torque, using more powerful magnets, minimal changes in the rotor housing and small adjustments in the number of windings of the segments.

Updated Converters (2 pcs.) for handling higher amperage from 7.0MW generator, including updated inverter modules, updated interface boxes between generator and converter as well as improved cooling. The converter converts the higher level of alternating current from the generator to DC, and then converts direct current to alternating current for full synchronization with the grid.

Larger transformer and new voltage variant to handle the higher power from the generator / converter. The transformer is located, as in the 6.0MW WTG, in the nacelle, in order to minimize the power losses which appear in the low-voltage cable connection in the tower, if the transformer was placed in the bottom of the tower.

In the 6.0MW WTG, the transformer can accept grid voltages from 10kV to 36kV depending on the site, through transformer variants.

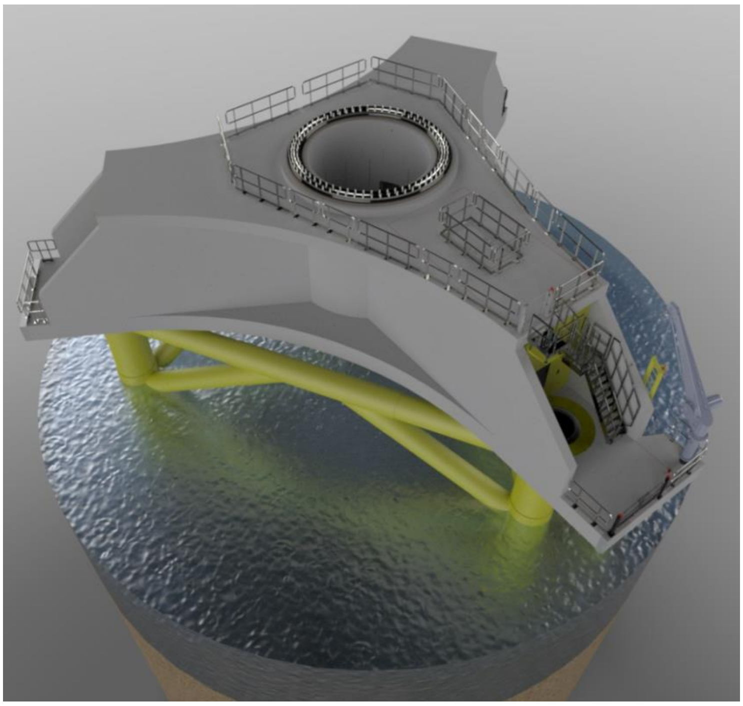
In the 7.0MW WTG, the transformer is larger and heavier in order to cover the same grid voltage range, and with the 7.0MW turbine we now have the possibility to use another transformer type covering the 72kV voltage level. This variant transformer is physically larger and heavier, but both sizes of transformers (10kV-36kV to 72kV) fit into the same outline of the design within the WTG. The increased weights are handled by minimal updates on the supporting structure of the WTG.
End test of the 7.0MW WTG at the NBV site in the 72kV range (66kV) is an important test possibility for SWP in an offshore look-alike environment for future wind farms.

Cable structure between generator/convertors and Converters/transformer (in the Nacelle) will be improved to cater for the larger power transmission.

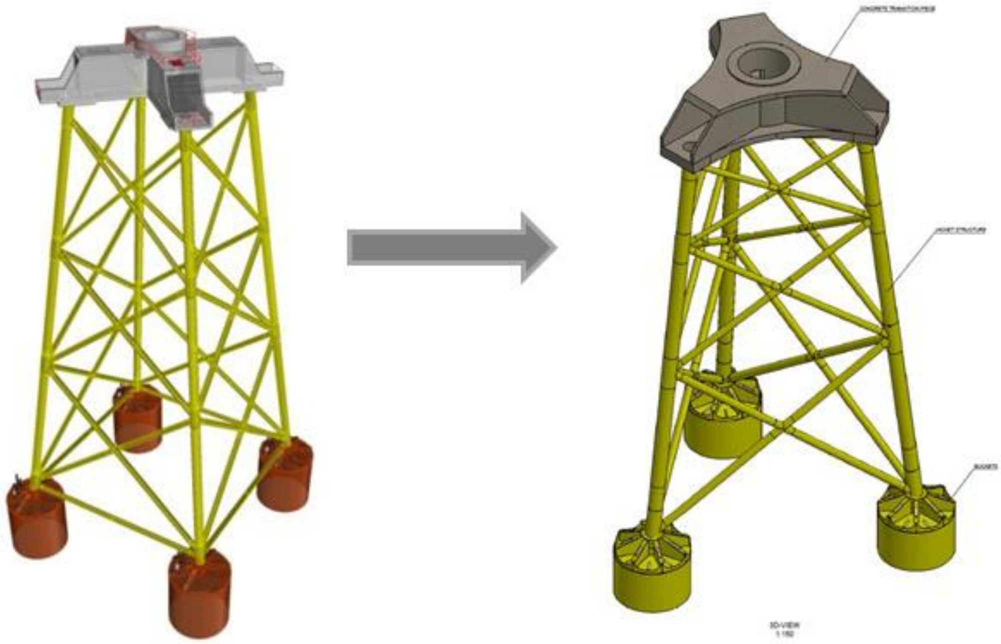
Updated Canopy Hatch. The outer shell (Canopy) on the 7.0MW WTG is reused from the 6.0MW model. The only change is that a large hatch at the bottom of canopy around transformer is changed in shape, to allow room for the 7 MW/72kV transformer. The Hatch in both the 6MW and the 7MW is designed to allow for replacing the transformer on site, without having to take the whole nacelle down again, in case of an unexpected failure of the transformer. This will reduce the service costs significantly.

The programme allow for manufacturing the first set of main components including pre-assembling in Esbjerg to be able to incorporate the learning and test the improvement in the connecting with the last 3 set of main components in order to obtain ensure a smooth series production for the upcoming projects. The Blades are not part of the o-series activities as we will used the B75 blades also used on the D6.

3. Element #2 - Prototype type test of SWP Gravity Foundation



In parallel to the Nissum Bredning project (NBV), the development of the full scale jacket is ongoing and incorporates the findings and design updates derived from NBV where applicable. The structure has therefore been changed from a four to a three legged structure with the corresponding changes in the TP structure.



3.1 Current Status of Support Structure

Ramboell has been selected as designer and is progressing as fast as the reception of input data allows. The design of the support structure has been adapted in several design iterations based on the environmental inputs, amongst others, results from the geotechnical survey and the identified ice conditions. Additionally, DNV is already involved in order to secure that the input data for the design are sufficient and interpreted correctly.

We are in detailed discussions with suppliers for all of the main components and they are involved in the optimization of the structure.

3.2 Geotechnical investigations

The time critical onsite drilling campaign has been completed for all foundations on October 4th 2016. Drillings were performed down to -65m to ensure a full picture of the soil conditions, which proved to be very complex. The drillings were followed by a series of advanced laboratory tests and the results were fed into the design process.

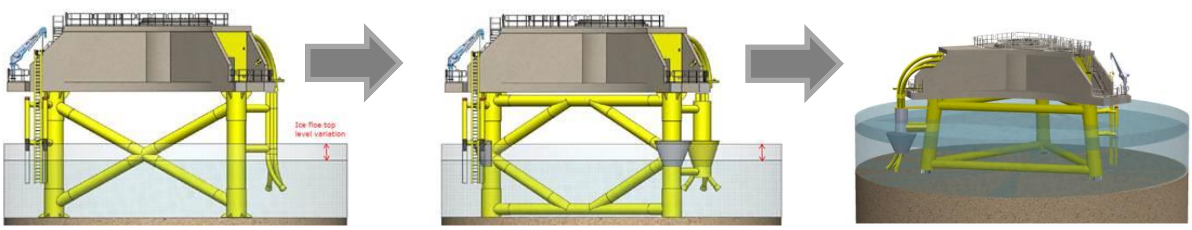
The obtained information indicated a seabed improvement requirement e.g. by replacing top layers down to -8 meters of seabed with a stone bed. The foundations have therefore been raised to a level of -2.5 to -3 meters, which will minimize the environmental impact in relation to seabed modification.

Scour protection is expected to be required on some locations.

Barge with drilling rig on site, September 2016

3.3 Ice Loads

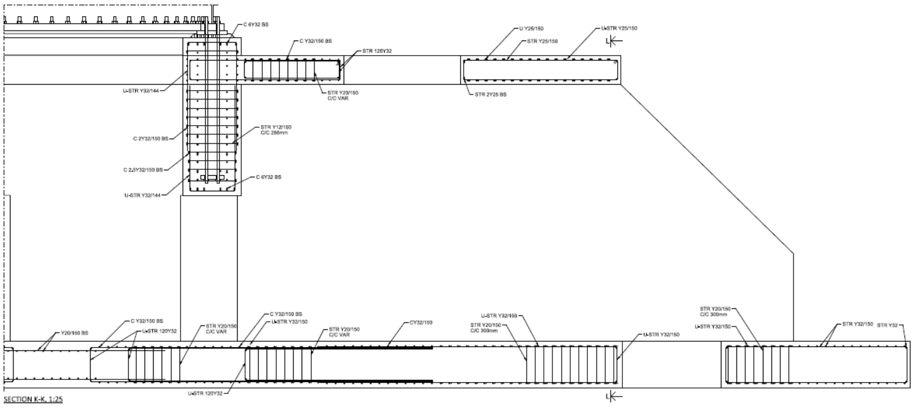
Severe ice loads were identified. The original concept with the x-bracing applied high load on the structure and to optimize this concept was changed to a "diamond" which still increased required steel to by a factor 2 to 3. The 3rd concept with inclined legs is now introduced with the necessary ice cones.



Multiple geometries to cope with ice conditions

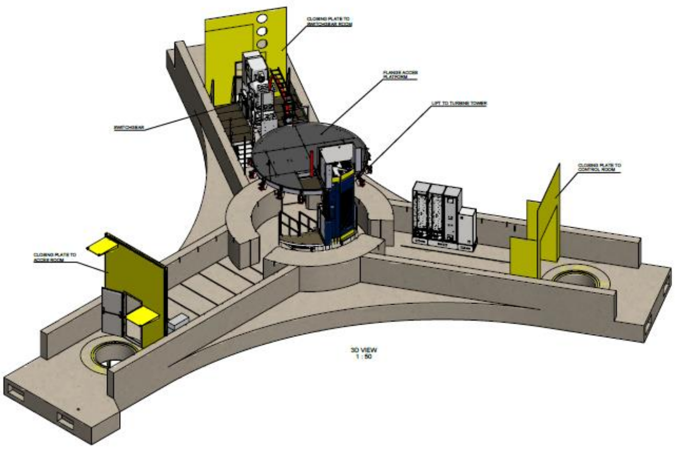
3.4 Concrete Transition Piece (TP)

The design of the TP structure is a tree arms approximately 1,100 Tons concrete structure providing the weight required to provide the gravity function.



Reinforcement layout

The tree armed TP has been arranged in a way allowing direct access from the vessel into a protected environment (Service arm) inside the TP ensuring a safe work place. From the entrance deck there is as well a stair providing safe access to the upper deck. The entire indoor part of the TP is humidity controlled and lightened securing a comfortable work environment. The high voltage equipment is placed in a separate arm providing access control. From the center piece of the TP a lift provides access to the upper part of the wind turbine.



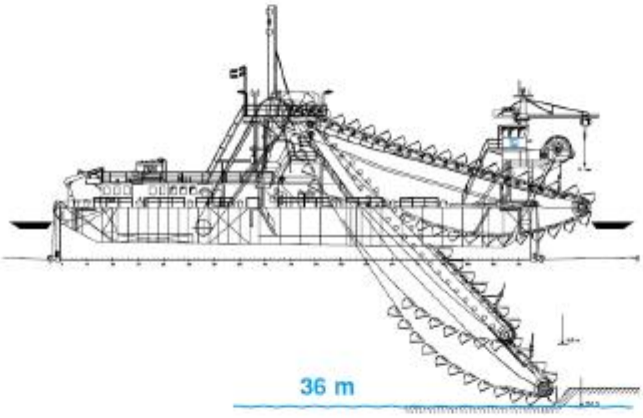
TP internals arrangement

The TP will be casted in one piece directly is based on being casted in one piece directly on a transport barge positioned at a portside concrete production plant. The TPs will be fitted out with electrical components before off-shore installation.

3.5 Logistics and Installation

The installation method is close to being finalized focusing on using the simplest possible setup. The main elements in the installation setup are:

- Dredging equipment to create access to the shallow areas



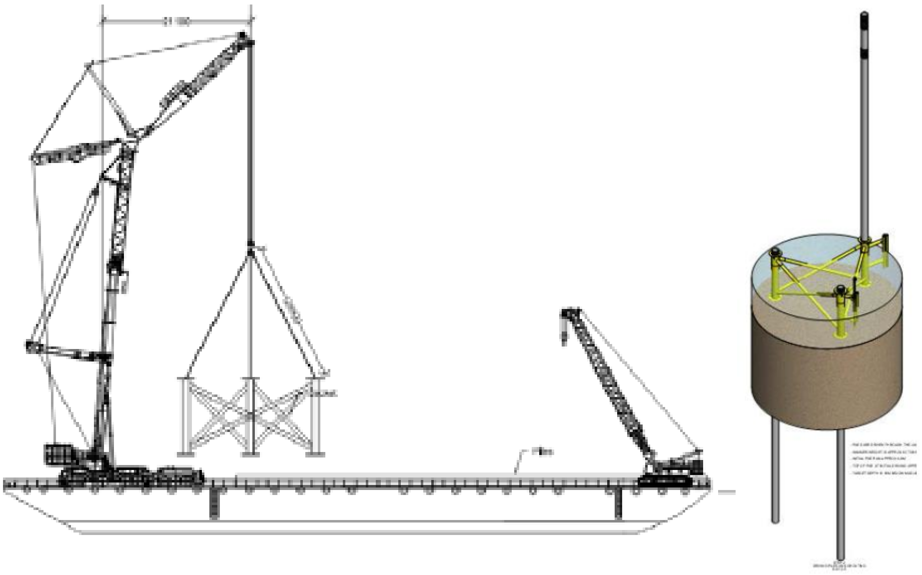
Principal Dimensions

Gross tonnage	587	GT
Depth	3,57	m
Draught	2,68	m
Length overall	51,26	m
Breadth	11,75	m
Dredging depth	36	m
Bucket capacity	700	lt
Power installed	560	kW
Max speed	27	buckets/min
Crew	7	
Flag		Dutch
Class		Germanischer Lloyd

Bucket dredger vessel for excavation works

To follow the new practice introduced by SVANA and Kystdirektoratet in relation to disposal the removed material within the construction area (by-pass method) we are investigation the possibility to by-pass the material around the turbine area and thereby reducing the noise distribution level in connection to piling. Required consequential analyses are being processed and will be discussed directly with Kystdirektoratet.

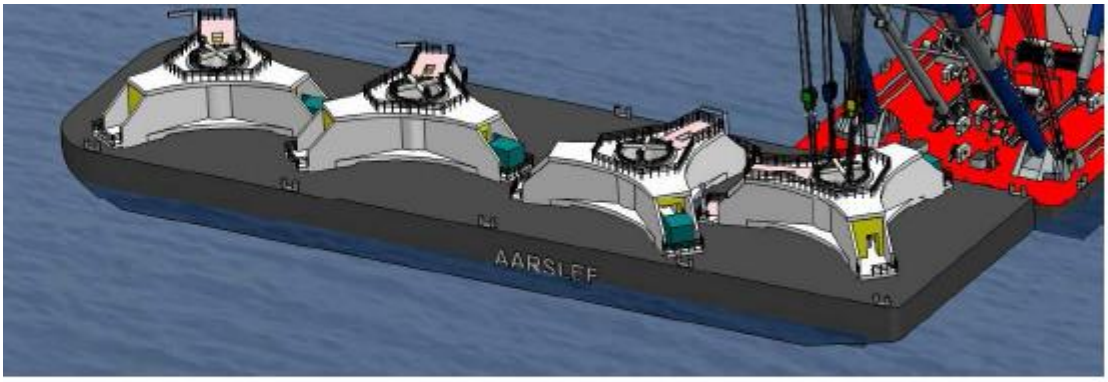
- Installation sequence of jackets and piles



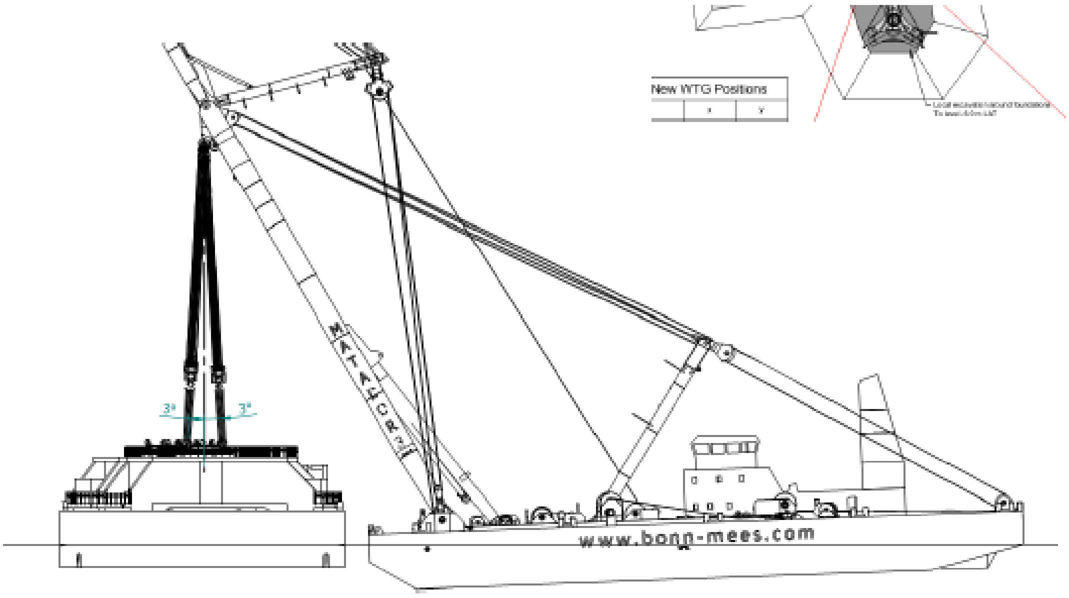
Lift-off and placing of jacket onto the seabed and install the piles through the legs of the jacket

- Installation of transition pieces (TP).

TP's are planned to be casted directly on a barge on which they subsequently will be transported to site and lifted into position.



Preliminary deck layout for TPs



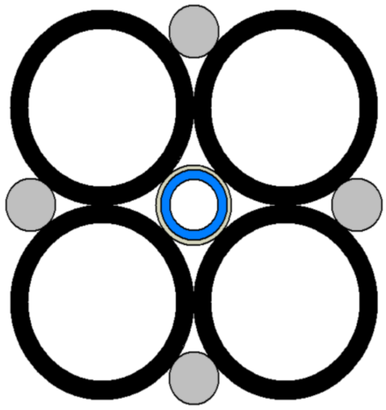
Installation of TP onsite

4. Element #3 - Prototype of Slender Tower Concept (5.5m)

A lattice structure such as a jacket foundation is by nature very stiff. To obtain an acceptable stiffness of the overall support structure from nacelle to seabed, a softer tower than what is typically applied on, i.e. monopiles is required to reduce the fatigue damages in the structure. SWP has developed a more slender tower concept with a diameter at the bottom of 0.5-1.0m smaller and up to 100 tons lighter than what is typically seen in today's wind farms. The issues with such slender structure are primarily the interface to the foundation, access into the WTG as well as space for internals in the tower

5. Element #4 - Prototype test cables in Pipes (CIP)

The Siemens cable in pipe concept will be introduced on this project. The concept involves the pre-installation of HDPE (High Density Polyethylene) pipes in the seabed, via horizontal drilling and/or laying/trenching or jetting.
Five HDPE pipes will be installed in a combined bundle for three single phase cables – one in each pipe and one pipe for fiber installation plus one spare pipe. The power cables and fibers will be installed in the pipes after pipe installation between shore and the foundations – and foundation to foundation.



Example of HDPE bundle design

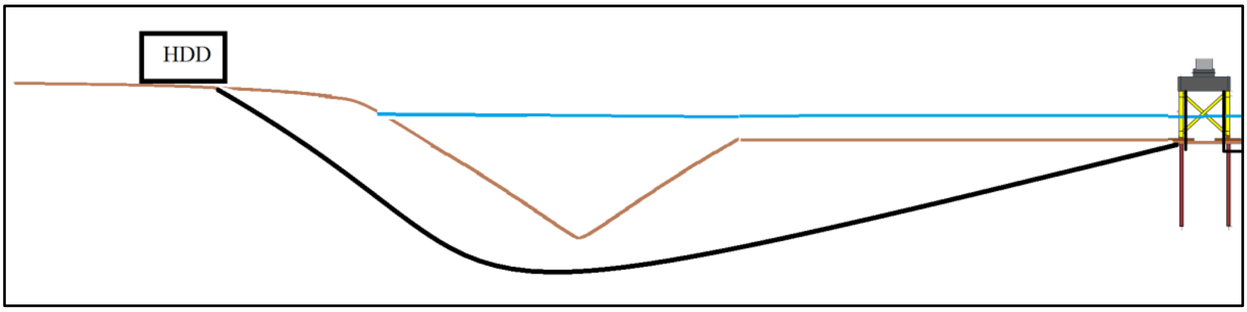
5.1 Main components concept

Main components of the onshore cable in pipes concept:

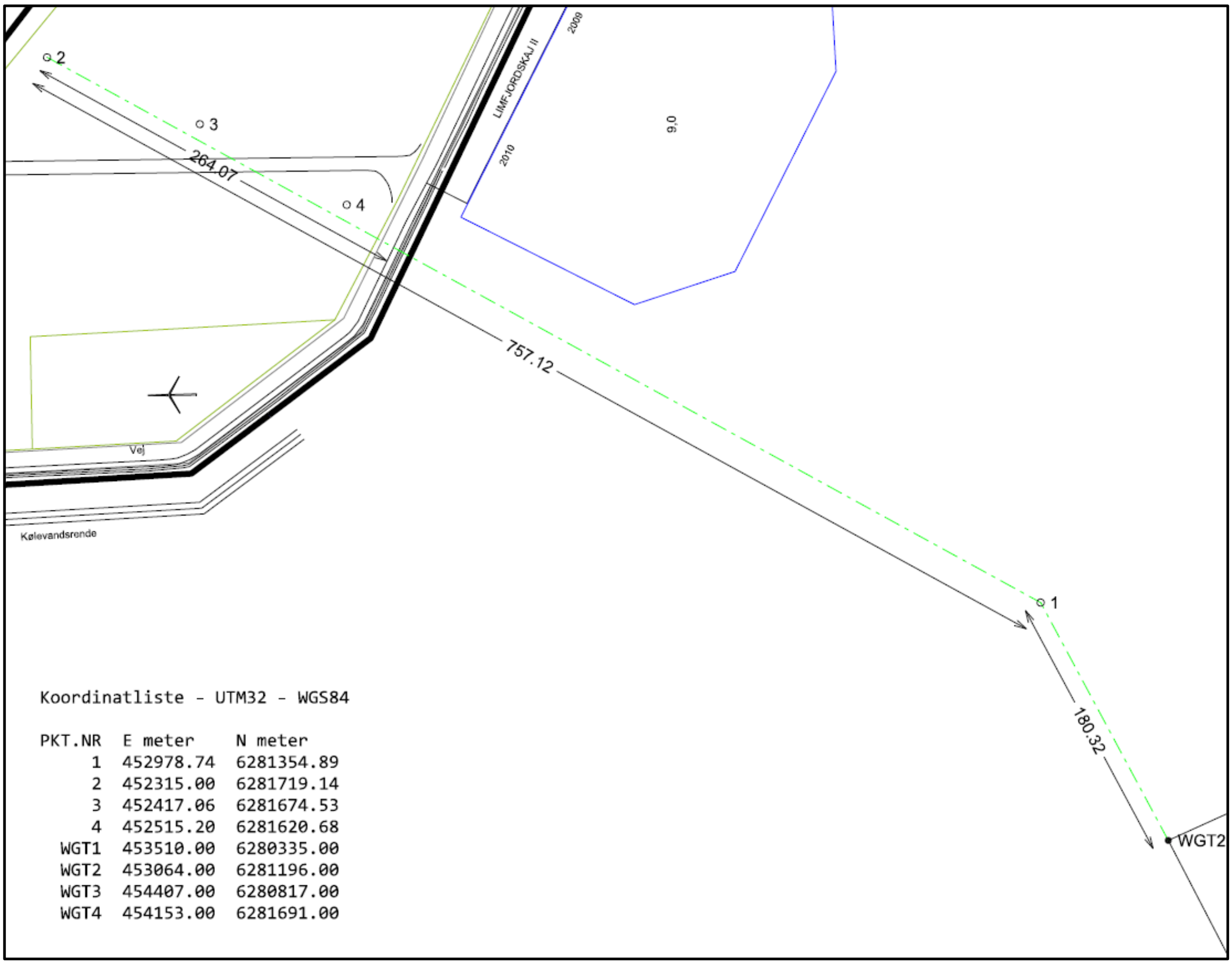
- Onshore cable type in a “Off the shelf” available design and size.
- Standard High Density Polyethylene (HDPE)
- Standard cable fasteners for securing of cable
- Use of Horizontal Directional Drilling for the Export Cables
- Installation of Export and Array power cables by means of “float in solution” – Watucab Machine, developed by Swiss company Plumettaz
- Post lay Burial of HDPE bundle/cables by standard jetting method

5.2 Geometry and Elevations

Water depth at the windfarm site is assumed to be between 2-7m. The Export ducts and cables have to be installed under the dredged shipping channel Sælhundeløbet with a designed depth of up to 60 meters below sea level, see sketch below. The latest proposed route is passing under the new Thyboroen South Harbor area and required extension will be considered into the design together with Kystdirektoratets possible extension for the sail route (200. from Centerline of existing sailing route)



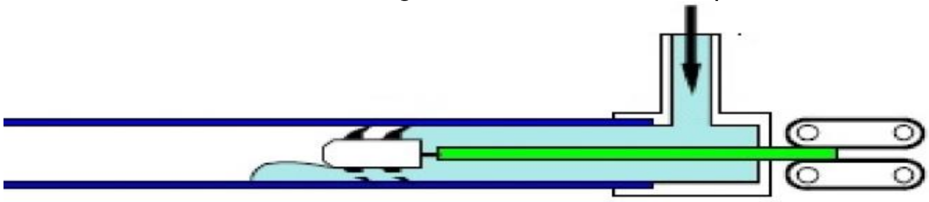
Sketch showing the HDD



Proposed of HDD plan

5.3 Installation

Installation of HDPE pipes will be performed in 2 different methods
a) Cables between turbines: Pipe HDPE bundle will be surface lay on the seafloor with a barge setup and supporting vessels. Post laid burial of HDPE pipes will be done by jetting tool.
b) Export cable: Horizontal Directional Drilling (HDD) will be performed from Connecting Point (on land) to WTG 2 location app. 1 km - the HDPE pipe bundle will be pulled back from WTG 2 location to connecting point.
After the HDPE pipe bundles are pulled into the TP via the J-tube power cables and fiber optic cable installation will be done from shore concerning the export cable part by means of Watucab machine and Array cables from foundation to foundation using the Watucab machine positioned on the foundation.



Watucab installation method

Watucab machine installing cable

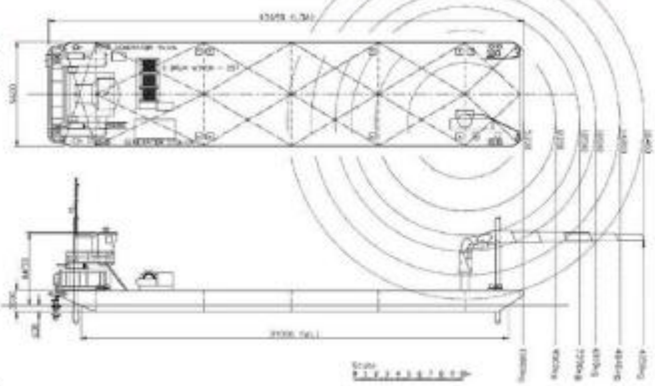
Horizontal Directional drilling of app 1 km, in an area with similar sub-ground conditions, has not been performed previously. Should it be proven during installation that HDD is not possible, we have mitigated the possible delay, related to redesign of alternative installation method as per above pos. 5.3 a), by planning the HHD activities early in the installation phase.
Connection Point (interface the grid supplier) and proposed HDD plan is shown in section 5.2

JD-Contractor A/S
Nybovej 8-9
DK-7500 Holstebro
+45 97 42 63 11
www.jdcon.com
VAT DK 16 93 56 97

S/B VICTOR

GENERAL		DIMENSIONS			MACHINERY		
Name	Victor	Length		43.0 m	Azimuth	2X	320 kW
Call sign	OXBW	Breadth		9.5 m	thrusters		
IMO number	8985543	Height (8 m reduced)		13 m	Aux. engines	1X	300 kW
Flag	Danish	Loading Capacity manned		180 mt		1X	9 kW
Built	1981	Loading Capacity unmanned		320 mt	Fuel type	Marine gasoil	
Classification	BV	Free Deck area (25 X 9)		225 m²	Fuel	60 l/hour	
Max speed	7 knots	Tonnage Gross		64mt			
Service speed	5 knots	Tonnage Gross		215 mt	Tow winch	1X	25 mt
Crew (min)	2	Draft light / max	0.9 m	2 m	Mooring	4X	450 m
Passengers	10	Crane m/mt	2m/28 mt	15m/4 mt	Spud legs	2X	12 m

Crane reach								
Kg	28.450	14.500	10.800	8.350	6.700	5.600	4.650	4.05
Radius	2,2	4,75	6,2	7,8	9,45	11,1	13,2	15,1



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Pipe barge - Barge Data Sheets

6. Element #5 - 66 (72kV) kV cables and switchgear solution

Testing the 66 kV (72kV) voltage level for offshore WTGs at a large-scale wind farm is essential for the future. Future sizes of wind turbines will require as a minimum this voltage level to enable cable sizes that are manageable by installation vessels. The NBV project with a 66kV (72kV) solution will be an important step for the development of larger WTGs.

By applying a 72kV system in larger offshore wind farms will give us the possibility to reduce the cost of energy, because the amount of high voltage cables between WTGs and the substation can be reduced. This is due to the fact that more WTGs can be connected to the same connection to the substation. Instead of connecting typically five (5) WTGs per cable to the power station, we can now increase this up to 10 WTGs on the same cable system. The expected reduction by applying a 66kV (72kV) solution is approx. 0.5% of the electrical loss of the total annual production. The 66kV (72kV) switchgear and cable design inside the foundations and towers requires new solutions due to larger cable diameter and therefore larger bending radius than the normal 33 kV systems - such solutions are being developed.

7. Element #6 - Test of LIDAR power curve measurement

LIDAR has been part of prototype testing in several projects, including the 6MW WTG previously situated in Østerild. It has come to the point where it would be beneficial for the test system to be executed in a large-scale wind farm set-up.

One of the issues of LIDAR testing has been the increased uncertainty compared to that of a usual IEC test stand, and one of the measures to reduce the uncertainty is to increase the number of measuring points. In the case of NBV one (1) WTG will be fitted with different LIDAR systems.

The advantage of NBV is that the LIDAR measurements can be supplemented with an onshore met mast in the upwind direction from one of the prevailing wind directions in case the final test program would require it.

8. Element #7 - Synchronization of rotors - Visual appearance

Visual 'Noise' has been one of the focus areas in cases when WTGs can be seen from ashore. Various methods have been used to minimize the visual appearance of the wind farms such as linear arrays, etc.

The intention in this project is to synchronize the rotors and investigate whether this reduces the so-called visual impact of the WTGs. It is proposed to make a survey among persons in the area, after a test period where the rotors have been synchronized for period (e.g.2 weeks) and thereafter random for a similar period, to understand if any differences have been noticed among public observers. It will be considered to use members of Nissum Brednings Vindmøllelaug, as mail addresses are already available and therefore it represents a reliable source.

9. Element #8 - Optimized use of sensors and limitation of loads through reduced output from the WTG

It becomes more and more apparent that it will be necessary to decrease the number of visits to offshore WTGs in order to keep the operating costs down. Additional adverse weather which prevent us from attending a turbine is a large contributor to unavailable turbines

The project has identified 2 main areas to explore:

1) To develop system that provide better monitoring of the lubrication level of the main bearing system and thereby create time to plan visit to the turbine weeks or months ahead, without the risk of making damage to the main bearing.

2) To develop and test different strategies where the turbine or the array/export cables has a fault but the turbine will be allowed to continue production but with de-rated output, until a visit can be made or running in active island operation mode until the cables has been repaired.

10. Overall Time line

Due to unexpected high impact of Ice Load on the structural design together with the relative thin layer of stable material disclosed by the geotechnical survey a redesign if the Jacket has been necessary.
The needed time for the redesign is included in the following main milestone dates which also consider the Environmental assessment where the Seals breeding period is highly sensitive and therefore no piling activities are planned during the period from 15th May to 15th July 2017.

Milestone Description	Date
Contract signature obtained	OK
Order placed on Steel (Jacket)	Feb/2017
First WTG 0-serie manufacturing completed	Nov/2016
First WTG 0-Pre-assembeling in Esbjerg Completed	Dec/2016
Foundation Procurement and Manufacturing completed	Jun/2017
Start of HDD	Mar/2017
Start of Foundation Installation	Jul/2017
Start of WTG Installation	Aug/2017
Start of Cable Installation	Aug/2017
Construction Restriction Start	May/2017
Construction Restriction lifted	Sep/2017
Commissioning Windfarm Completed	Oct/2017
Wind Farm Take Over	Nov/2017
Test Element 6 - LIDAR completed	Apr/2018
Test Element 7 - Rotor synchronisation completed	Apr/2018
Test Element 6 - optimisation of sensors	Nov/2019