1. Forslag og ansøgere

a. Forslagstitel:

Nissum Bredning – Testbed for new technologies and integrated design.

b. Ansøgere og kontrakt personer

Nissum Bredning Vindmøllelaug I/S (NBV)

Rugvænget 3

7673 Harboøre

Denmark

Attn.: Jens Jørgen Birch

Jysk Energi A.m.b.a.

Skivevej 120

7500 Holstrebro

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Attn.: Lars Naur

Siemens Wind Power A/S (SWP)

Fiskergade 1

7100 Vejle

Denmark

Attn.: Jan Bøgelund Madsen

c. Øvrigt deltagende virksomheder/institutioner.

Several companies are participating in the project. Some are participating through the EUDP projects, which gives them a more direct involvement in the project, while others are sub-suppliers delivering parts of the project.
The following list is a non-exhaustive summary of the companies in question:

Through EUDP:

- Bladt
- Force
- NKT Cables.

Sub-suppliers:

- JD contractors
- Aarsleff
- Bladt
- Rambøll
- NKT Cables
- Wavin.

d. Tilskyndelsesvirkning

Any technology jump is expensive and time consuming. Bringing it from the drawing board to real life is in all cases an exhaustive and costly exercise which makes it difficult to introduce new technologies to a market where consistency and reliability are the most important qualities of business.

For many years, it has been possible to introduce new wind turbine (WTG) models at test sites; first at the test station at Risø, later at the test station in Høvsøre; and most recently, at the test station in Østerild. However, when the technology jump consists of the balance of plant (BOP) part of offshore wind farms, it has been left to the individual developers to lift that burden – with varying results. Facing the difficulty of satisfying the financing institutions every time, the attempts of introducing new technology on the BOP, including technology research and development have been overlooked and neglected.

For the above reasons, the test project which NBV and SWP are attempting at the Nissum Bredning site is bold and ambitious – and is depending entirely on the subsidy provided in the 'Forsøgsordning' program. Even though four (4) turbines provide some scale compared to only one(1) WTG – the 'one off' costs are dominating and would in an 'Open Door' scenario make the project impossible to finance.

The total cost for establishing this test wind farm is expected to be approx.. 500 Million DKK – this is a estimated cost due to the outstanding soil investigations. Under the "Open Door" concept the IRR of this project would not be able to be financed by a normal "Vindmøllelaug". This is due to the high initial costs and the considerable risk element. SWP will be able to bridge part of that risk, but to make this project the support we could get for the 28 MW is a deal maker.

If this project was not to be built under this program, then at best, the technology jump would end up being delayed and at worst, never realized.

Even with the subsidy presented in this program, both companies fronting this application will invest more in this project than in any other traditional project, which only shows the dedication of the companies to participate in development that will set new standards for the cost of energy.

e. Andre tilskud

Elements of the foundation have been supported in the EUDP program, and this project is really the realization and natural follow up of the results of the EUDP program. The two EUDP

programs are;
'Automatic node welding' and 'New cable solutions'.

f. Sammenfatning

There are several parallel activities in the demonstration project at Nissum Bredning:

1. 0-series test of SWP 7.0MW WTGs
2. Test of LIDAR power curve warranty measurement
3. Syncronisation of rotors
4. Prototype type test of SWP Gravity Jacket
5. Prototype of Slender Tower Concept
6. Prototype test of cables.
7. 66kV cables and switchgear solution
8. Optimized use of sensors and limitation of loads through reduced output from the WTG.

Ad 1. 0-series test of SWP 7.0MW WTGs

At the moment, SWP is testing the 7MW WTG at the Østerild test stand. Before the turbine is finally released for serial production, SWP will initiate tests in an environment similar to that of the North Sea. The four(4) WTGs do not behave like in a large-scale wind farm in terms of turbulence, but the fact that the test site is situated just behind the Harboøre Tange means that turbulence is generated as though the WTGs were located in a wind farm.

The upgrade from 6.0MW to 7.0MW includes the following improvements:

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 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 greater 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.

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 Canpoy in the transformer is changed in shape, to allow room for the 72kV transformer. The Hatch in both the 6MW and the 7MW is designed to allow for switching 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.

Ad 2. Test of LIDAR power curve warranty 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 NBVup to three (3) WTGs will be fitted with LIDAR.

The advantage of NBVis that the LIDAR measurements can be supplemented with an onshore metmast in the upwind direction from one of the prevailing wind directions.

Ad 3. Syncronisation of rotors

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.

Ad 4. Prototype type test of SWP Gravity Jacket

The overall objective of our technological development is the reduction of Levelized Cost of Electricity (LCoE) from North Sea wind farms far from shore from currently EUR ~14.5 cent per kWh to below EUR 10 cent per kWh before 2020.

Since 2013, SWP has developed a novel state-of-the-art foundation concept for far-shore North Sea wind farms to push the foundation market to deliver incremental cost reductions. The structure consists of standard pipes, robot-welded nodes and a concrete transition piece forming the interface to the tower. For the interface to the seabed the suction bucket technology has been selected.

The concept development is still ongoing, but some of the technologies such as the concrete Transition Piece (TP), nodes and pipes are quite advanced in their development and are currently being assessed by DNV.

The NBVproject is an excellent opportunity to test and demonstrate a number of the key technologies in a small-scale project and in a controlled environment. The shallow water and very complex soil conditions dictate an alternative to the suction buckets as interface to the seabed. A concept with four long piles to take the transfer the compression loads and the heavy TP to minimize the compression seems to be optimum solution for the conditions at the NBVsite.

Beside testing key elements such as the concrete TP and robot-welded jacket nodes primarily for the deeper water North Sea locations, the new seabed interface solution may open up for other wind farm sites which were deemed out especially in the Baltic Sea due to pour soil conditions.

The proposed foundation concept and development timeline is described in Appendix *1 F – 4a (2015-10-05_Nissum Bredning - Foundation Solution.docx)* and Appendix *1 F – 4b 2015-10-07_Nissum_Bredning_Preliminary%20Technology%20Roadmap.pptx*

Ad 5. Prototype of Slender Tower Concept

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 1m-1.5m 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.

Ad 6. Prototype test of cables.

The cables and the cable connection to shore are very important parts in an offshore wind farm. Usually they individually do not count for a high percentage of the cost of a wind farm, but they do, however, count for a very high percentage of risk. Furthermore, the repair time of a failed sea cable is often very long and costly.

SWP has been exploring a method which could both reduce the risk and make repair easier and repair times shorter. This method includes a pre-lay of plastic pipes which then can be filled with a standard onshore cable after burial. In this way we reduce the risk of damaging the cable during laying the cable and a repair in case of a cable failure is easier and less costly.

Ad.7 66kV cables and switchgear solution

Testing the 66 kV 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 solution will be an important step for the development of larger WTGs.

By applying a 72kV transformer solution 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 sub station can be reduced. This is due to the fact that more WTGs can be connected to the same connection to the sub station. 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. The expected reduction by applying a 66kV solution is approx. 0.5% of the electrical loss of the total annual production.

Ad 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. One way of achieving this is among other things to increase the intelligence level of the wind turbine controller. – In other words – we need to know more about the status of the WTG. Knowing more about the status would enable us to develop new operating strategies so that the availability of the WTG can be increased. As the size of the WTGs goes up the necessity of increasing the availability of the WTGs becomes evident.

2. Minimumskriterier

a. Antal møller og driftstilskud

It has been chosen to erect the new SWP SWT-7.0-154 WTG in a four-turbine configuration to ensure an adequate scale to test all new features as encompassed for the WTG and Balance of Plant (BoP) test scheme.

The following table 2a-1 lists the main parameters for calculating the expected remuneration.

With the setup, the increased subsidy scheme is expected to support 1,365,744 MWh of electricity production, distributed on two subsidy schemes with a 30/70 split on full load equivalent operation and the rotor swept area.

The wind farm is expected to generate approx. 131,854 MWh per year.

Data Item	Value	Unit
Turbine Type:	SWT-7.0-154	
Power:	7	MW
No. Of Turbines:	4	pcs
Total Power	28	MW
Rotor Diameter:	154	m
Swept Area/WTG:	18617	m2
Subsidy Scheme:		
Subsidy Scheme 1, Duration - Full Load Equivalent:	15000	h
Subsidy Scheme 2, Power/m2 Swept Area:	12,7	MWh/m2
Subsidy Principles:		
Sum of subsidy and electricity market price:	0,70	DKK/kWh
Electricity to be sold on the Danish spot market		
No subsidy is offered when spot price is negative		
No reimbursement for balancing costs		
Expected annual energy production (AEP)	131854	MWh
Wind Park:		
Electricity Production subject to Subsidy Scheme 1 (~30%):	420000	MWh
Electricity Production subject to Subsidy Scheme 2 (~70%):	945744	MWh
SUM (100%):	1365744	MWh
Table 2a-1		

The following table 2a-2 shows the estimated remuneration under the increased subsidy scheme.

The limit for the increased subsidy will be reached within the 10th year of operation in year 2027.

Calculated in 2014 prices, the accumulated total subsidy is expected to be DKK 350,996,105 following a total energy production of 1,365,744 MWh. The total remuneration (spot price plus subsidy) under the increased subsidy scheme is expected to be DKK 956,020,520 following a total energy production of 1,365,744 MWh.

Year*	AEP MWh	AEP Accumulated MWh	Accumulated MWh Under Subsidy Scheme***	Energinet Calculated Electricity Price DKK/MWh****	Estimated Subsidy** DKK/MWh	Subsidy Accumulated DKK	Total Remuneration (Spot Price + Subsidy) per Year DKK*****	Total Remuneration (Spot Price + Subsidy) Accumulated DKK
2017	65927	65927	65927	292	408	kr. 26.885.789	kr. 46.148.900	kr. 46.148.900
2018	131854	197781	197781	340	360	kr. 71.176.306	kr. 92.297.800	kr. 138.446.700
2019	131854	329635	329635	388	312	kr. 102.825.409	kr. 92.297.800	kr. 230.744.500
2020	131854	461489	461489	436	264	kr. 121.833.096	kr. 92.297.800	kr. 323.042.300
2021	131854	593343	593343	437	263	kr. 156.049.209	kr. 92.297.800	kr. 415.340.100
2022	131854	725197	725197	438	262	kr. 190.001.614	kr. 92.297.800	kr. 507.637.900
2023	131854	857051	857051	439	261	kr. 223.690.311	kr. 92.297.800	kr. 599.935.700
2024	131854	988905	988905	440	260	kr. 257.115.300	kr. 92.297.800	kr. 692.233.500
2025	131854	1120759	1120759	441	259	kr. 290.276.581	kr. 92.297.800	kr. 784.531.300
2026	131854	1252613	1252613	442	258	kr. 323.174.154	kr. 92.297.800	kr. 876.829.100
2027	131854	1384467	1365744	443	257	kr. 350.996.105	kr. 92.297.800	kr. 956.020.520
2028	131854	1516321	1365744	444	256	kr. 350.996.105	kr. 92.297.800	kr. 956.020.520

** Assumed project take over date, July 1, 2017. Yet TBD.*
*** Subsidy assumed as difference between 0,70 DKK/kWh and electricity spot price at the given time.*
**** Final increased subsidy payment is due in year 2027, limited to 1365744 MWh of production*
*****Energinet data in 2014 pricing. 2017 to 2018 prices are extrapolated. Prises from 2020 are derived by/from Energinet's BID/SIVAEL models.*
****** Future cash flows/renumerations have not been discounted to present value*

Electricity spot prices are based on Energinet's 2014-2035 analysis, updated September 2014

Table 2a-2: Estimated remuneration under increased subsidy scheme for near shore test sites.

2 b. Forsøgsområdet

The test area is in Nissum Bredning close to the town of Thyborøn. Appendix 2 b - 1 contains the 'Forundsøgelses tilladelsen'. Appendix 2 b - 2 contains the lay-out with indication of wind turbine lay-out.

Calculation of AEP is available in Appendix 2 b – 3

2 c Økonomisk og teknisk kapacitet.

In this project, the parties have chosen a model where NBV is responsible for the permits and for acquiring the site, while SWP is responsible for all technical aspects. NBV will remain as owner of the project after the project has been installed by SWP on a turn-key basis. The agreements between the parties involve a testing agreement so that testing parts of this program is included.

The organizational and financing structure of NBV is shown in Appendix 2 c – 1. As it appears from the appendix, NBV is backed by individuals and companies having many years of experience within wind farm development and they have brought the project to where it is today; a project where the EIA
(Environmental Impact Assessment) requires only minor adjustments and the site is ready to go for final development in respect of the 4 x 7MW WTGs.

Siemens Wind Power has a long list of references, some of which are illustrated in Appendix 2 c– 2.

3. Udvælgelseskriterier.

3 a. Beskrivelse af forsøgets udviklingspotentiale

In this wind farm, several tests are performed involving all elements in the offshore wind farm.

The content can be described as follows:

Wind turbine (WTG):

The tests on the turbine are related to the future increase in size and reliability of WTGs. Secondly, we are testing a cost-effective way of performing power curve testing; a facility which has requested ever since the first offshore wind farms were established.

Traditionally, the tower is a part of the WTG. However, in this case it is a part of the foundation and in a much lighter version due to the integrated design.

Foundation:
The foundation concepts have previously been focusing on gravity, monopile and jacket foundations. With the exception of the gravity foundation, the other foundation types have been inherited from the oil and gas industry. This means that the design does not have its offset in

WTG loads and characteristics. In this project, we are using a foundation design that tries to bridge the gap between what is known and is working both in the oil and gas industry as well as in the offshore wind turbine industry so that we maintain the reliability and construction friendliness. We consider this foundation to be a new step in the right direction and it is also aiming at future WTG sizes due to the scale ability and huge development potential. No doubt, this foundation will be the new starting point for future optimizations relating to different WTG types and soil types due to the cost effectiveness of the design.

Cables:
Hardly any offshore wind farms have been constructed without experiencing a cable fault. These faults have either been related to the laying of the cables or to the design of the cables. Furthermore, the cables have been suffering from the fact that the armoring has limited the current-carrying capacity of the cables as well as the thermal stability of the cables. In this project, we take advantage of a system that has been used onshore and scale it for offshore application. By using the cable-in-pipe-principle we do not have to use steel-armored cables, but standard onshore cables and this also means that the laying of the cables is exchanged with laying of pipes. It is apparent that this principle will be directly applicable in the array cable segment, but we are aiming at expanding this principle to the grid cable as well. There are some obstacles we want to pursue further; that is the repair or exchange of a defective cable. Right now, the method descriptions suffer from a lack of practical approach which should describe how this can be done in a cost-effective manner. Please observe the attached video from a testi at Thyborøn Harbor.

3 b. Beskrivelse af kommercielt perspektiv.

The individual components in the proposed test program will each have a significant impact on the existing offshore market. NBV and SWP expect that the introduction of the technologies promoted in this program will increase the offshore market since it will enable more projects to obtain financing or and open the opportunity for new sites. For instance the Baltic area it will open up for sites where it would have been close to impossible to establish a wind farm based on today's technology.

On the Danish market, we create a potential for lowering the price of the BOP cost in future offshore projects. We expect a decrease of up to 12.4 % in the costs; primarily on sites with higher water depths (Table 3 c -1). On the global market, the simple effect is that the number of offshore potential projects will increase due to the fact that more projects will be financially viable.

The designs we are considering in this project are all expected to be certifiable. There has been contact with certifying authorities and no major obstacles have been identified during the discussions.

For any prototype version, a serious task is to reach a maturity level enabling serial production of the prototype model – this is in order to get the full benefit of any cost reduction potential that has been encompassed in the design. In the 0-series program all the method descriptions will have to be established both from SWP's side as well as from all the sub-suppliers.

Existing tools such as B-Hawc will have to be adapted to include the new designs. This is a part of this project as well.

3 c. Målgruppe og merværdi for brugerne.

This project aims at supporting all future developers of offshore wind farms. It addresses fundamental cost drivers in the BOP and supports the development of more reliable WTGs able to perform better in the offshore environment.

The cost improvements can either be used to reduce the cost of energy or be used to increase the market by supporting a technical solution for the more complex sites. In table 3 c -1 an overview of the potential savings in this project can be found:

Table 3 c -1

Item	Saving potential		
	in % of item	*in % of CAPEX*	*in % of OPEX*
Cables	-30%	-2,50%	-2,50%
Foundation	-25%	-9%	0%
WTG Tower	-25%	-1%	0%
WTG _Sensor/Algoritme	5%	0,10%	-10%
Total		-12,40%	-12,50%