



## **ABOUT WindSea**

### **An introduction**

WindSea AS is established to develop, test and commercialize the WindSea floating windmill system. WindSea is owned by FORCE Technology and NLI both leading players in their respective fields.

WindSea is a new concept for offshore wind mills. The concept is developed using the gained experience in the offshore industry. In particular fabrication, access, installation, and maintenance are key issues the concept will address.

The WindSea concept consists of a floating device supporting 3 wind mills.

The configuration of the floater is of semi-submersible vessel type with 3 corner columns. Each column supports one wind mill.

The semi-submersible vessel is moored to the sea bottom and the mooring lines are connected to a turret at the vessel geometric centre allowing the vessel to rotate. The vessel is therefore able to always orient the turbines optimally towards the incoming wind.

Due to the large diameters of the mills and the relative small dimension of the vessel one of the mills will be partly in the shadow of the 2 others. To minimize this shadow effect the tower of the downwind mill is made higher.

The ability of the vessel to rotate, leads to the advantage that the turbines do not need a traditional yaw-system to rotate them individually, but can be fixed in the same position, this reduces cost.

This leads to two consequences: the power shall be exported through a swivel; a turret shall be installed in the vessel.

As a sum up of this short description, the features which characterize the WindSea concept and make it different to the other concepts are: configuration of the 3 turbines partly in shadow, electrical connection through a swivel, mooring lines connected to a turret.

### **Further development**

- The development phase that started in Q1 2010, includes further studies and engineering work, optimization of the concept etc. prior to initialising start of fabrication of the prototype as well as testing.
- The prototype phase includes detail engineering, fabrication, procurement, commissioning and installation at a test location.

- After the installation of the prototype, there will be a test phase at the test location leading up to full commercialisation of the WindSea system.

### **The purpose of WindSea**

The purpose of WindSea is to develop, test and commercialise a floating offshore wind turbine for the global market. The global energy demand cannot be met by fossil energy sources alone. At the same time, fossil energy sources are a significant source to the climatic challenges we are currently facing. Globally, focus is on developing clean and renewable energy sources and this makes wind energy an important player.

However, establishing wind turbine farms is far from smooth. Factors such as preservation of nature, limited space and disagreements as to where wind turbine farms should be placed constitute a huge challenge. Offshore wind turbine farms address some of these problems, which is also one of the purposes of developing WindSea.

### **The advantages of WindSea**

Today, a number of offshore wind turbine farms exist, however, they differ significantly from WindSea. The bottom fixed foundation concepts for offshore windmills can only be installed at sea depths of maximum 40-60 m, whereas some floating concepts require water depths at 110-130 m. As the WindSea concept requires only approximately 45m water, the large market with water depth ranging from 45-120m depth, the WindSea system can be utilized, which will be filled in by WindSea. In practise, there are no limits to the depth at which WindSea can be installed.

Furthermore, there is a great financial profit to be gained by being able to fully build and test WindSea on shore, and then tow it out to sea to be installed (Plug and Play).

### **Windsea - development phases**

The development of WindSea is divided into phases. The first phase was the Validation of Concept and the last is construction, installation and operation of a full scale pilot with a generator capacity of 3 x 3.6 MW. Currently the WindSea project has completed the Validation of Concept phase with excellent results. During this period extensive analyses has been performed, both with internal and external competences. Further, extensive model tests has been performed including tests in water tank, wind tunnel and combined wind exposed tests in water tank. The Validation of Concept phase focused on some of the technical challenges connected with floating offshore wind turbines. The test results were positive, and the project moved on to the next phase, which focused on optimising the concept prior to construction of the prototype, addressing and overcoming the remaining challenges.

### **Technical and financial challenges**

Globally, there are today relatively few mature offshore wind turbines. Regularity has been a challenge, since not all technical problems connected with offshore wind turbines have been fully realised – such as wrecks and gear box problems. Floating offshore wind turbines are also much more movable, which require much more of the equipment such as generators, gearboxes, etc. Furthermore, the choice of correct materials also plays an important role, as the risk of corrosion is much higher offshore than onshore. Included in the WindSea design is more than 30 years experience for design of floaters. By utilising this huge experience the design gives predictable and smooth movements in all sea conditions, also combined with the effects of the turbines. In reality the turbines give smoothening effects, which is a positive

spin off of effect of the design. As a consequence of this, standard offshore turbines from the turbine fabricators can be used with the estimated same regularity as for standard turbines.

Based on the present design and the utilisation of medium size turbine installation of 3 x 3, 6 MW, the present calculations show that the concept will be able to produce electrical energy at competitive cost.

### **Conclusions**

The main conclusion is that the tests have confirmed the expected behaviour of the vessel.

For the given wind parameters it has been proved that the effect of the wind on the vessel motions is small, and that the effect of the motion on the power output of the turbines is negligible.

The tests results are compliant with the results obtained by Risø and the calculations performed by the project team.

A more extensive tests program for testing other wave-wind combination together with a more optimal model of the turbines may also be undertaken on the basis of those results.

For the Ekofisk field data a design of the WindSea concept has been developed.

Critical components (turret, electrical connection for power export, anchors and mooring lines) have been designed successfully using proven technology.

The wake effect and turbulence action on the downwind turbine have been calculated. Those investigations conclude on the feasibility of the chosen wind turbine configuration.

Model tests in wind tunnel and wave basin have confirmed the validity of the design and of the calculation made.

The calculated power production for the Ekofisk wind data is of 41,4 GWh/year which represents 93% of the production of three 3,6 MW standing alone turbines.

It is concluded that the WindSea concept has been verified and validated.

The present design is a sound basis for further development.

# CONCEPT

## Characteristics

- Semi submersible platform with 3 columns
- Three turbines
- The floater is self orientating towards wind
- Mooring lines connect to a disconnectable turret
- Cable for power transmission is guided through the turret to the seabed

## Advantages

### Construction

- Flexible layout – scalable
- Easy fabrication – all construction is performed at yard, including installation of the turbines
- Easy installation – the floater is tugged to offshore destination, connected to the mooring lines and ready for operation (Plug and Play)

### Energy Production/Operation

- Cost effective solution – three turbines on one platform
- Self orientating towards the wind – wind and wave response is independent of each other

### Maintenance

- Easy access for inspection and maintenance as well as space to perform such tasks
- May easily be disconnected from the turret and tugged to the yard for modification or more extensive maintenance

## Dimensions

- Height upwind turbines above sea level: 71 m
- Height downwind turbines above sea level: 90 m
- Distance between upwind turbines: 103 m
- Turbine power: 3,6MW each, total 10,8 MW – rotor dia: 104 m
- Vessel draft: 23m (operation) 7m (at yard)

## Development

### History

- 2006 – 2008: Concept development
- 2008 – 2009: Validation of concept: Optimization of the concept

Extensive calculations and analysis performed by WindSea and external specialist companies (RISØ DTU etc.)

Test performed in water tank: The marine performance of the vessel, power production at different sea conditions as well as the ability to self orientating towards the wind.

Test performed in wind tunnel: Power production including the effect of wake and turbulence.

Test performed in water tank with wind exposure (combined water tank / wind tunnel test)

### Results

- The main principal of the WindSea floater has been proved correct. Validation of Concept successfully concluded.
- The total energy production for a given configuration has been calculated
- The power production of the system has been calculated and verified in test to be 93% of the theoretical maximum, based on three stand alone turbines
- Wake effect: The results from the test and WindSea`s calculations are in accordance with third party calculations (RISØ)
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### Total energy production and wake losses

The results presented are taken from the study performed by Risø. Those results have been corroborated by analyses performed by the project and by the model tests. The Risø analysis cover the whole range of wind speed (from 5 m/sec to 27 m/sec) while own analyses and model tests are performed only for specific wind speeds.

The power production versus the main wind speed at 10 m above sea level is presented in figure 5.1. The figure presents two curves the higher curve is for the downwind turbine standing alone while the lower one is for the downwind turbine accounting for the wake effect (shadow) from the two upwind turbines.

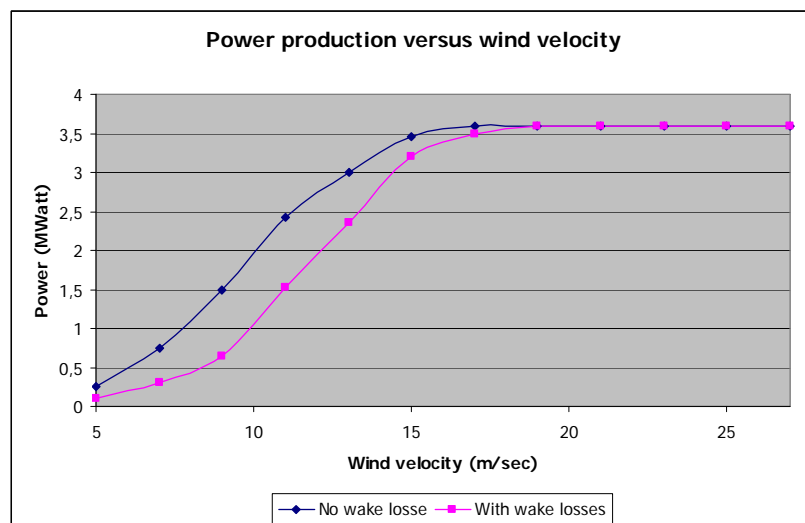


Figure: Power production for the downwind turbine

The loss of power due to the wake effect is most significant for the low velocity in the range of 7 m/sec to 13 m/sec, while for high velocities the power production is almost unchanged. It should be noted that the curves are dependent on the turbine properties and on the relative positions of the 3 turbines. By a suitable choice of turbines and positions the gap between the two curves may be reduced.

The total power produced by the turbine in a year is obtained by the combination of the power produced for each wind velocity and the probability of occurrence of this velocity.

By doing this operation for the two curves and taken the ratio of the two obtained numbers, the total power production reduction due to the wake may be calculated.

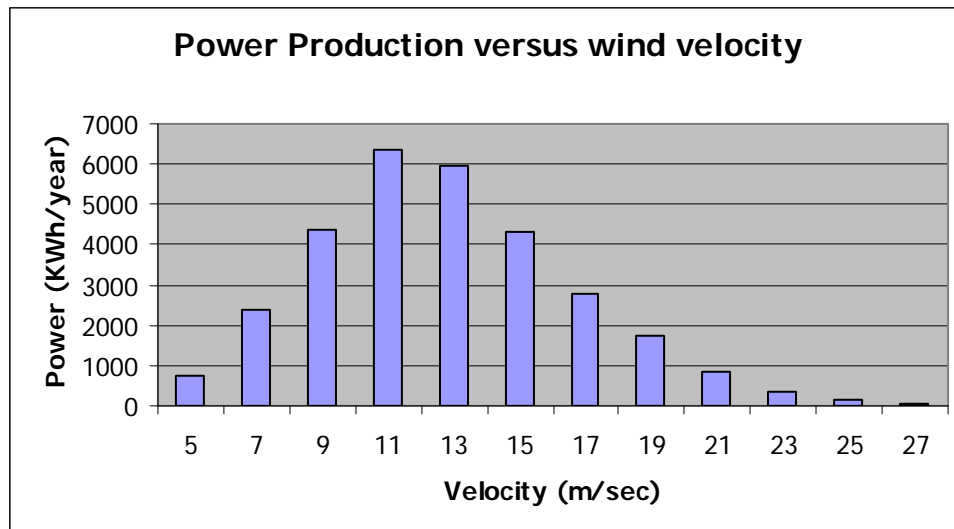
Risø has calculated this ratio for the given configuration to be 75% for the rear turbine. For the two turbines in front, there are no negative interaction between the two, hence this is calculated to 100 % for both.

Based on those production curves, the environmental data from Ekofisk and the down time of 15% (this value is documented in the System Engineering activity) the power production for the 3 turbines is calculated to be in the range of 14,8 GWh/year for the 2 upwind turbines and 11,7 GWh/year for the downwind turbine.

This gives a total production of 41,4 GWh/year.

The production value is 93% of the maximal production of 3 like turbines ( $3 \times 14,8 = 44,5$  GWh/year).

The figure shows the distribution of the power production as a function of wind velocity. The most of the power is produced for the velocity between 9 m/sec and 18m/sec.



### System Engineering

The electrical scheme for the power export of the three turbines has been outlined. No difficulties are expected for the realisation of the system.

The export cable has to be lead through the turret. The cable can not be designed to be twisted. Therefore to avoid that the WindSea vessel has to be rotated back to its original orientation, a swivel is designed to be installed.

The project has has investigated the availability of a swivel with the required capacity in the market and concluded positively i.e. a swivel with the required capacity and characteristics are commercially available and suitable for use.

It is also concluded that the WindSea main principle (ability to rotate against the wind) is proven to be technically feasible.

High focus has, however, also been on the downwind turbine.

As a consequence, the use of three upwind turbines has been investigated. The rear tower is, in this configuration, erected to be in a vertical position and hence an upwind turbine can be utilized. The investigations performed concludes that there are no foreseen negative effects technically or for the calculated and tested power production, based on the same wind data etc.

The analyses performed by Risø simulate the air flow behind the two upwind turbines including the general meandering of the flow and the local turbulences created by the turbine blades. The forces on the downwind mill are calculated: forces on the blades, the rotor, and the tower.

The analyses show that the effect of the turbulences created by the wake results in a marginal increase of the forces and fatigue damage in the main components of the mill. It was intuitively expected that the effect should be larger. Further investigation to explain this result should be done in the future.

However the main conclusion of the Risø investigation is that the required strength for the main components of the downwind turbine can be achieved using standard available components.

An important issue is the availability of the power production. Offshore environment made intervention and maintenance more difficult, and the availability of the turbine may be less.

By using Markov theory simplified availability analyses has been performed. Fault rate statistics of high quality is hard to obtain. The availability analyses are based on a Germany statistic with historical data from 1994 to 2004 for onshore wind turbines. The wind turbines have gone through a major development during those years.

If shutdown of one upwind turbine result in a shutdown of the other upwind turbine due to stability reasons the considering generator capacity on board Windsea has an overall availability of 85,2 %. In those analyses the contingency in both fault rate and the prospected repair time is significant due to lack of operation experience of offshore wind turbines mounted on floaters.

Due to the system consisting of three wind turbines the control system has to integrate three single control system of each turbine. Interaction of the turbines like common starting, shutdown etc. must be a part of the control system.

The control system can also be extended to control the turbines to stabilize the direction of the platform to ensure that the upwind turbines are headed against the wind. Design proposal deliver ideas for further activities since the design of this control system presents a complex challenge.

Especially operational aspects have to be investigated but its feasibility does not seem to be a problem.

### **Structural Engineering**

Based on the main geometry given by the marine activities (motion and stability criteria) the steel layout of the vessel has been developed.

The forces due to wave, current and wind including inertia forces as well as the self weight and buoyancy have been applied on a computer model of the platform. A beam element model in Sesam has been used.

The model is restrained at the attachment to the mooring line.

The stiffness analysis has been performed for 28 waves distributed into 9 directions. The waves represent the 100-year event and the event expected to give the maximum internal forces in the structure. In a later stage more waves should be investigated to verify that the maximum loads for each location has been picked up.

All calculation are done according the NORSOK code.

The stresses in all part of the structure are also computed and the dimensioning of each main part of the vessel is performed.

No fatigue analysis for the overall structure has been performed at this stage. However the fatigue sensitive locations have been identify as shown in the figure 5.3.

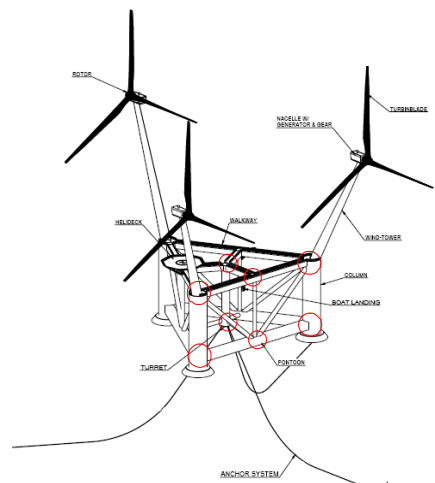


Figure: Fatigue sensitive areas

Fatigue analysis of the towers due to wind and inertia forces has been done, since those areas are anticipated to be the most fatigue loaded. The towers are subjected to different loading conditions: the turbines may be activated or not. The fatigue damage created when the turbines are not in use has been calculated for 20 years life time.

A probabilistic analysis method has been used and the damage calculated to 0,079. In its analysis, Risø has estimate the fatigue damage created when the turbines are in use.

Risø pointed out that the proposed design of the tower has the drawback to have an eigenfrequency in the range of the frequency activated by the rotation of the rotor. Risø has therefore proposed to reinforce the tower to avoid this situation. Based on this new design the fatigue damage was calculated to 0,57.

From those evaluations it may be concluded that the fatigue is not expected to be a major issue in the design of the vessel.

Finally the vessel has been checked for resisting a boat impact. The standard criteria as described in NORSOK have been used.

As a result a total steel weight has been calculated.

Total steel weight is about 4600 t exclusive the nacelles but inclusive the towers.

Total displacement of the vessel at operating draft: 9200 t.

### **Motion and stability analyses**

This activity has focus on the definition of the overall dimension of the vessel and on the prediction of the motion when the WindSea vessel is subjected to wave and wind excitation.

The stability criteria are given by the DNV rules for mobile units. Its leads to the main dimension for the vessel: distance between columns 75 m, columns diameter 9 m.

The pontoon diameter is given by the requirement of floating to a draft of 6-8 m for make possible the entry in harbour.

The motion has been calculated with the computer software Sesam (Wadam).

Two alternatives have been studied: one with skirts attached at the lower end of each columns and one without skirt.

The function of those skirts is to increase the damping of the system and consequently reduce the motion of the vessel.

The study shows that the skirts do reduce the motion in heave (vertical motion) but have no significant effect for the pitch motion (rotation around an axis perpendicular to the wave direction).

To determine the anchor forces non linear in time domain analyses have been performed using the software Simo.

The effect of the wind on the vessel motion was more difficult to assess. In this case in contrary to the common floating devices the wind forces are significant compared to the wave forces: typically 150 t for the wind compared to a total of about 700 t.

The analysis of the wind action on the turbines shows that the frequencies are in range of 0,2 Hz and above. The frequency for the pitch and surge motion are in the range of 0.05 Hz and below. Due to this large separation in the frequencies it is concluded that the two effects may be analysed separately and summarized using RMS method.

### **Stability**

WindSea satisfies the DNV rules and regulations with respect to stability during in-place condition. Maximum static heel angle is 4.3° and 9.5° during normal working condition and 35m/s wind speed storm respectively. WindSea also has acceptable stability characteristics when flooding of compartments occur during operation.

During transit it is assumed that the waterline is intersecting the pontoon (no ballast). In this configuration WindSea has high stiffness and good stability, and therefore satisfies the DNV rules and regulations for both intact and damaged condition.

#### Motion

The motion analyses show promising results for the extreme (100 year event) condition. The following maximum responses have been estimated:

Heave 10.3 m  
Pitch 6.2 degrees  
Roll 5.4 degrees

The above values relate to WindSea without skirt dampers. The following maximum response was found when skirts were mounted on the platform columns:

Heave 11.7 m  
Pitch 11.8 degrees  
Roll 11.6 degrees

These results indicate that skirts not necessarily improve the motion characteristics of the floater. It was however found that the air gap was reduced by the inclusion of skirts. For the operating condition with wind the following maximum responses have been estimated (without skirts only):

Heave 3.2 m  
Pitch 5.2 degrees  
Roll marginal, head sea/wind only

An important design criterion for a semi-submersible unit is the split force acting on the column and pontoons. Investigations of split forces show that maximum occur for a wavelength of about 115-120m. This wave length is some 10 m less than one normally expects for conventional semi's using approximately twice breadth measured between the outer the pontoons. The reason is purely geometrical; WindSea has a triangular footprint as oppose to traditional rectangular hulls.

#### Mooring

The mooring system design is governed by the small water depth required which calls for a complex configuration to obtain required flexibility of the system. An iterative design approach was performed varying between different configurations to obtain a layout that not would influence the wave frequent motion of the platform severely. Among other a limiting criteria was the assumption that the fiber rope not should have bottom contact. However if this assumption can be invalidated, using fibre only may be feasible and would be an improvement of overall mooring system

First of all it has to be pointed out that the motion response of the platform is very moderate with the current mooring system. This is the case for both operational and storm conditions. Analyses show a maximum offset of about 14.5 m and a mooring load of 830 tonne.

#### Self Up-righting Capacity

This report shows preliminary calculations of the mechanical self up righting system of the WindSea platform. After having investigated various shapes of the aft tower, the drop shape has been concluded compatible compared to other shapes. The reason are given below.

Up righting characteristics: due to the geometry, the up righting characteristics are significantly better than the semi aerofoil and the ellipse shape.  
Fabrication: the drop shape is easy to fabricate as plates can be connected to a circular tower giving the outside drop shape.

## **Mooring and Turret design**

### Mooring

The mooring and anchor system required for the entire platform can be based on proven equipment and available technology. Consequently, there is not seen any major technology risk related to the mooring system.

Optimisation of the system can only be made when the installation site has been defined. Water depth and soil condition have to be known. As soon as the soil conditions are known, the anchor type can be defined. Cost optimisation will include anchor and mooring lines as a whole.

The prototype mooring system is designed with a total of 6 mooring lines. The design includes 3 clusters separated 120° and 2 lines in each cluster separated by 10°. This design is chosen to meet the requirement of "one line rupture without drifting off" (ISO and DnV).

The Ekofisk area is used in the validation and cost calculation, which means 70 meter water depth and soil conditions where suction anchors are suitable.

A wind farm installation has a significant cost savings opportunity combining one anchor for as much as 3 mooring lines. The challenge is related to the anchor design. In a wind farm with a total of three mooring lines for each platform, only two lines will remain in operation if one mooring line ruptures. In this situation, the platform will drift off until the two mooring lines take the load. The load acting on the anchor will change direction by approx 120°.

This requirement is foreseen be possible to solve by a modification of the suction anchor or other anchor types available in the market (DPA etc) .anchor or other anchor types available in the market (DPA etc).

The DPA anchor (Deep Penetration Anchor) is a low cost option and can be used in a wide range of soil conditions, but not for Ekofisk. DPA is a relatively new development, now under final certification and testing. DPA is the most promising design to take load in different directions and thereby suitable for a 3 mooring line solution.

The DPA anchor should be considered also for the prototype installation if the soil conditions are within the acceptable criteria.

### Turret

The turret system is the mechanical and electrical interface between the entire platform and the mooring-/anchoring system. The turret system will give the platform full capability to rotate while connected to a geostationary mooring system. The turret is also the entry point for electrical high voltage power cable to the platform.

The turret will have functionality for disconnection and reconnection of the platform from the mooring system.

The turret required for WindSea can be based on proven design principles. Vendors having years of relevant experience will be able to design the WindSea turret.

Consequently, there is not seen any major technology risk related to the turret system

### **Fabrication**

Fabrication of the WindSea platform can be performed in a number of ways. The overall philosophy is that the most cost effective fabrication method fulfilling the fabrication criteria should be chosen. The following gives backup for this information.

#### Hull including Wind Mills

Fabrication of the hull can be split and carried out at a number of yards, and the final assembly performed at a central place. This also includes systems to be included in the hull and wind mills.

It should be noted that the fully equipped platform will be able to float at a draft of 6 to 7 m having a GM in the order of 12 m. This allows for the possibility of both dock and inshore fabrication/assembly.

Tow-out of the platform to field will be done by tug boats. Further ballasting of the hull to achieve a greater water depth is foreseen.

#### Helideck

The helideck is considered to be part of the hull equipment.

#### Wind mills

As for the Helideck the windmill towers steel structures are considered to be part of the hull equipment. The windmill supplier is assumed to be involved in installation of the equipment in the towers.

#### Anchors

The positioning of the anchors is considered not to be critical as installation within a range of 0.5 to 1 m should be easy to achieve and this will be far within the acceptable range.

#### Turret

The turret can be installed immediately after installation of anchors and mooring system. The turret will be fabricated and machined as one unit and fully tested for easy connection/disconnection with the platform at the assembly yard.

### **Maintenance**

The Windsea platform is designed to be disconnected from the mooring lines and towed to shore for major maintenance work. This will be performed on a bi-yearly basis or when major equipment requires service or repair.

The following inspection and maintenance areas are foreseen:

- Anchors,
- Anchor lines
- Turret
- Hull
- Wind Mills
- Helideck

- General vessel equipment

For each item the level and the frequency of required maintenance has to be identify.

All needs have to be summarized and coordinated such that the number of intervention on the vessel may be minimized.

It is possible to conceive of a number of plausible Operation & Maintenance (O&M) strategies for Windsea installations.

There are two different types of maintenance action:

Preventive Maintenance (PM) aims to reduce the occurrence of failures

Corrective Maintenance (CM) that involves action only after a failure has occurred.

Any approach to maintenance can employ, either or a combination of both of these actions.

Each attempts to balance capital costs, operational costs, and energy production in a different way. In considering the ideas, it is important to remember that our objective is to minimize the cost of the electricity produced by the offshore farm. This is not the same as maximizing the energy production, and indeed the most economic scheme may be one which sacrifices a little electricity for a great reduction in maintenance costs.

In practice, all wind turbine concepts are likely to have teething troubles at their introduction. For a period immediately after the construction of a wind farm, say 6 months, a special commissioning maintenance regime would have to be in operation until the teething troubles were ironed out. For the subsequent mainstream operation, the following maintenance strategies have been identified:

- The no-maintenance strategy
- The only-CM-maintenance strategy
- The opportunity-maintenance strategy
- The PM & CM maintenance strategy
- The light-PM and light-CM maintenance strategy
- The periodic check maintenance strategy

It also of first importance to choice the O&M strategy at the project start since this will govern the choice of the technology used.

### **Model tests**

Model test have been performed both in wind tunnel and in wave basin.

In the frame of the validation phase the tests were conducted to verify the main principles of the WindSea concept and validate the calculation methods used during design.

The model tests do not covers all ranges of wind speed and sea state, but are performed for specific data.

# BEHIND WindSea

## **FORCE Technology Norway and NLI**

The two co-operating companies, FORCE Technology Norway and NLI, will play significant and important roles in the coming phases. Both companies, being in the technical forefront within their fields, are foreseen to contribute both in the validation, engineering and construction phases.

## **About FORCE Technology**

FORCE Technology's mission is to safeguard lives and assets in a sustainable manner and protect values that create values.

FORCE Technology's operation within Oil & Gas contains several specialized environments that focus primarily on servicing the offshore industry.

Their competence is built on a solid foundation with 30 years of experience within innovative development and use of knowledge and technology.

FORCE offer their customers unique competitive advantages through their flexible, innovative and value added solutions that are based on confidence and close cooperation, which adds value to both parties.

FORCE Technology is in possession of world class technologies and experience within the area of structural integrity. They want to be the customer's preferred collaborative partner in projects with high degree of specialist knowledge, and they want to participate in these projects from the early conceptual phase to the delivery of a turnkey project.

Since their origin as The Danish Welding institute in 1939, FORCE has developed into one of northern Europe's leading research and technology hubs. FORCE is represented in Norway, Denmark, Sweden, USA and Russia and employees about 1200 skilled people.

## **About NLI**

NLI is an industrial company supplying engineering and fabrication services, technology products and process solutions to the following market areas; oil & gas, industrial plants, maritime industry as well as bridges and buildings/infrastructure. NLI undertake the complete responsibility from concept development to manufactured product.

NLI has approximately 800 highly qualified employees and anticipates a revenue for 2010 of 1 billion NOK.

NLI Innovation is an Industrial Development Company, combining NLI's industrial knowhow and capacity with seed capital. NLI Innovation also provides services within concept development, industrialization and management. Their aim is to play an active part in concept and product development within the following market areas:

- Oil and Gas
- Renewable Energy
- Carbon Capture Storage