Stiesdal Offshore Technologies

TetraSpar and TetraBase

Industrialized Offshore Wind Turbine Foundations

Henrik Stiesdal, February 1, 2019
Framework

Company Structure
• Climate technology company with focused subsidiaries

Purpose
• Combat climate change by developing and commercializing solutions to key challenges

Project
Target
Means

Stiesdal A/S
Stiesdal Offshore Technologies A/S
Stiesdal Storage Technologies A/S
Stiesdal Fuel Technologies A/S

Tetra
Unlimited low-cost offshore wind energy
Industrialized fixed & floating foundations

GridScale
Unlimited share of renewables on grid
Storage system w. 10h – 10d capacity

SkyClean
Carbon capture and sequestration
Carbon-negative jet fuel
Offshore wind can deliver all the electricity we need

If offshore wind in Northern Europe would be the only source of electricity for the EU …

- EU load: 2.800 Bn. kWh/year
- Offshore wind energy per sea surface area: 30 kWh/m²/year
- Area required: 90,000 km²

- Pre-Brexit EU (pop. 500 million) could be supplied 100% by nine offshore wind farms, each measuring 100 km x 100 km
Offshore wind is competitive

Source: Berkeley National Lab
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The European offshore wind market develops accordingly

Source: WindEurope
But there is a snag -

Offshore wind as we know it is only applicable in selected locations
• Maximum water depth of fixed foundations 40-50 m
• Can be applied in Northern Europe, off China and off US East Coast
• Most other population centers have much too deep nearshore waters

Source: NOAA
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The solution – floating offshore wind power
The California offshore wind potential

• Total CA installed capacity 80 GW (2015)
• Total CA generation 200,000 GWh (2015)
• Gross potential CA floating wind capacity 573 GW
• Gross potential CA floating wind generation 2,000,000 GWh @ 40% CF
• Gross CA floating wind potential equals 10 times current CA generation

Source: NREL
The Japan offshore wind potential

Japan has plenty of Wind Energy Resources at onshore & offshore

Available Energy:
- Onshore: 210GW
- Fixed offshore: 156GW
- Floating offshore: 300GW
- Total: 666GW

Conditions:
- Average wind speed at 80m height:
  - Onshore: 6.0m/s >
  - Fixed offshore: 7.0m/s >
  - Floating offshore: 7.5m/s >
- Capacity/area conversion at 10,000 kW/1km²
- Considering particular social conditions

Sources: JWPA
But again – there is a snag: Floaters are not industrialized

Shared characteristics
- Very heavy – from 2500 tons to 10,000 tons for 7 MW class turbines
- Construction methods from shipbuilding and offshore oil and gas sector
- Fabrication typically at port of floater launch
- Build times typically measured in months
- Tens of thousands of man-hours per foundation for steel cutting, fitting, welding, handling, etc.

Picture credits: Siemens, Principle Power, Hitachi, U.Maine, MHI, Mitsui
The first truly industrialized product – Ford Model T

1909

1923

Source: Ford Motor Company
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The power of industrialization is huge

Source: Ford Motor Company
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Taking advantage of a world champion …

The humble wind turbine tower

- Probably the world’s lowest cost per kg of any large steel structure
- High quality welds and surface protection
- More than 20,000 towers manufactured annually in highly industrialized processes

How did we get there?

- Separation of fabrication and installation
- Modularization and standardization
- No IP of any significance – costs kept low through open competition

Picture credit: Danish Wind Turbine Manufacturers’ Association
Enter TetraSpar – floating wind power industrialized the onshore way

Mindset
• Conventional thinking
  • We have designed this structure – now, how do we build it?
• TetraSpar thinking
  • We need to manufacture this way – now, how do we design it?

Concept
• Modular – all components factory-made, transported by road
• Components assembled at quayside, just like the turbine is assembled
• Turbine mounted in harbor and towed to site, no installation vessels
• Weight 1200-1800 t for 8 MW turbine
The fundamental choice on the supply chain thinking

The learning curve

We can start here ...

Or we can start here ...

Relative cost

100%

10%

1 10 100 1000 10000 100000 1000000

Total number of units produced

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Road transportation is easy and low-cost!

Welcon A/S
- Leading manufacturer of offshore wind towers
- Has supplied around 50% of all offshore wind towers in the world
- Located about as far from the sea as you can get in Denmark

Conclusion
- Other factors (stable workforce, easy expansion) are more important than transportation distance
Solution for overseas ports

Multipurpose vessel type

- Gross tonnage 10,000 t
- Draft 7 m
- 960 vessels with necessary crane capacity
- 15 carriers operating globally, none with more than 15% market share
- Capable of carrying both tower and floater for 10 MW turbine
- Esbjerg – Brest round trip duration 10 days including loading/unloading and 2 days weather contingency
The special configuration of TetraSpar

- Easy towing to site using only tugs – no installation vessel required
- Very shallow draft in port and during towing
- Simple catenary mooring system
- Deployment of stabilizing keel after hook-up to mooring
- Ballasting of keel turns foundation into spar with very attractive dynamic properties
- Can also be implemented as semisub or as TLP at water depths (40-80 m) too shallow for spar version
- Keel can be de-ballasted and elevated to sea level for periodic inspection
- Easy decommissioning by reversal of installation process
TetraSpar installation process

Installation and tow-out, keel mounted below floater

Hook-up to pre-laid mooring on arrival at site

Initial ballasting of keel to deploy pre-mounted keel lines

Full ballasting of keel, converting floater from semisub to spar
TetraSpar is available in several configurations

- The keel arrangement of TetraSpar enables the spar configuration

- However, the keel is not the defining feature of the concept. Other configurations are available also, including a TLP and a semisubmersible

- The defining feature of the concept is the industrialized manufacturing
Target cost trajectory for TetraSpar

Lines/markers indicate the median expert response for the **median LCOE scenario**
Shaded areas show the 1st-3rd quartiles of expert responses

Source: DoE, NREL, IEA
2017 model tests, carried out by DTU in DHI wave basin
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TetraSpar Project stages

**Stage 1 - 2016**
- Concept
- Initial validation

**Stage 2 - 2017**
- Design
- Tank test OK

**Prototype**
- Siemens SWT-3.6-130, 3.6 MW rated power, 130 m rotor diameter
- Status 20.11.18: Final design close to completion, installation scheduled for April, 2019
- Foundation contractor: Welcon
- Installation contractor: Maersk

**Stage 3 - 2020**
- Prototype
- Full validation

**Stage 4 - 2021**
- Pilot project
- Release

€ 0.2m

€ 18m
TetraSpar industrialization concept applied in fixed foundation

TetraSpar

TetraBase
Key features shared by TetraSpar and TetraBase

• Can be adapted to any turbine size and any water depth – TetraBase for 10-60 m water depths, TetraSpar for 40-1000+ m water depths
• Fully industrialized, utilizing existing tower-manufacturing supply chain
• All components factory-made, no special processes (welding, painting, etc.) outside factory environment
• Fast and robust assembly in port of embarkation; no facilities needed other than a flat area at quayside
• Easy launch using slip or semisubmersible barge
• Turbine installation at quayside using land-based crane
• Pre-commissioning at quayside possible
• Easy towing to site using conventional vessels
TetraBase offers a unique installation method

- One-stop installation – foundation and turbine installed in one simple process
- No separate vessel mobilization for foundation installation and turbine installation, and no installation vessel required at any stage of process
- Seabed preparation limited to levelling of pad areas
- Gravity stabilized in most condition - no piling required
- Eminently suited for rocky seabed
- Piled or suction bucket variants can be applied when seabed conditions do not allow gravity foundations
- Where piling is required, piles will be limited to three pin-piles
- Easy decommissioning by reversal of installation process
TetraBase installation process

Foundation set on seabed in port for turbine installation
Temporary tanks de-ballasted for towing to site
After arrival on site, temporary tanks ballasted to set down foundation
Foundation water-ballasted and temporary tanks floated off
Cost benefits of TetraBase relative to monopile

Foundation and installation costs
8 MW WTG, 500 MW project, 35 m depth

Monopile

TetraBase

Decommissioning
Commissioning
Turbine installation
Foundation installation
Seabed / scour
Harbor operations
Logistics
TP
Foundation
TetraBase Project one year later than TetraSpar, same release date

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The Tetra technology can be applied at all water depths
Thanks for your attention

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Introduction – Henrik Stiesdal

Former CTO of Siemens Wind Power, retired end 2014

Key Achievements

- Wind power pioneer, built first test turbine 1976, and first commercial turbine 1978; licensed wind turbine design to Vestas 1979, kick-starting modern Danish wind industry
- Served as technical manager of Bonus Energy A/S from 1988, ran company together with CEO until Siemens acquisition 2004, then took position as CTO of Siemens Wind Power
- Installed world’s first offshore wind farm (1991) and world’s first floating wind turbine (2009)
- Invented and implemented key technologies, including Siemens proprietary blade manufacturing, low-weight direct-drive turbines, variable-speed operation, energy storage, etc.
- Holds more than 800 patents

Post-Siemens activities include work on low-cost offshore infrastructure, high-capacity energy storage and carbon-negative fuels