Experimental study of the DTU 10 MW wind turbine on a TLP floater in waves and wind

Bredmose, Henrik; Mikkelsen, Robert Flemming; Hansen, Anders Mandrup; Laugesen, Robert; Heilskov, Nicolai; Jensen, Bjarne; Kirkegaard, Jens

Publication date:
2015

Citation (APA):
Experimental study of the DTU 10 MW wind turbine on a TLP floater in waves and wind

Henrik Bremose, Robert Mikkelsen, Anders Mandrup Hansen, Robert Laugesen
DTU Wind Energy
hbre@dtu.dk

Nicolai Heilskov, Bjarne Jensen, Jens Kirkegaard
DHI

Part of the INNWIND.EU project
Scaling principles for floating wind turbine tests I

Define a length scale ratio

\[ \lambda = \frac{L_p}{L_m} \]

Gravity is dominant!
Ratio of force to gravity is preserved

\[ \frac{M_p a_p}{M_p g} = \frac{M_m a_m}{M_m g} \quad \Rightarrow \quad a_p = a_m \]

Hereby time scale ratio is locked:

\[ \frac{T_p}{T_m} = \sqrt{\lambda} \quad \Leftarrow \quad \frac{L_p}{T_p^2} = \frac{L_m}{T_m^2} \]

Preserve ratio of structural and fluid mass

\[ \frac{M_p}{\rho_{wp} V_{lp}} = \frac{M_m}{\rho_{wm} V_{lm}} \quad \Rightarrow \quad \frac{M_p}{M_m} = \frac{\rho_{wp}}{\rho_{wm}} \lambda^3 \]

Classical Froude scaling of mass, length and time. Well known for wave tank tests.
Scaling of rotor properties

Froude scaling of hydrodynamics:

\[ \lambda = \frac{L_p}{L_m} \quad \frac{T_p}{T_m} = \sqrt{\lambda} \quad \frac{M_p}{M_m} = \frac{\rho_{wp}}{\rho_{wm}} \lambda^3 \]

Keep overall geometry

Keep consistent scaling of rotational frequency

\[ R_{rotor,m} = \frac{R_{rotor,p}}{\lambda} \]

\[ \omega_m = \frac{\omega_p}{\sqrt{\lambda}} \]

Preserve tip speed ratio

\[ \frac{\text{TSR}_p}{\text{TSR}_m} = \frac{\omega_p R_p}{u_{ap}} \frac{u_{am}}{\omega_m R_m} = 1 \]

\[ \Rightarrow \quad u_{a,m} = \frac{u_{a,p}}{\sqrt{\lambda}} \]

Thrust force and thrust coefficient

\[ F_T = \rho_a C_T A u_a^2 \sim \rho_w \lambda^3 \]

\[ \Rightarrow \quad \frac{C_{Tp}}{C_{Tm}} = \frac{\rho_{wp}}{\rho_{wm}} \]
Air velocities (model scale) $\sim 1.5$ m/s

Re (proto scale) $\sim 10M$

Re (model scale): $\sim 25k$

Not likely to scale correctly!
Preliminary results
Extreme environment

Preliminary results
Gentle environment

Setup and validation

Scaling principles
- Air velocities
  (model scale) \(\sim 1.5 \text{ m/s}\)
- \(Re\) (proto scale) \(\sim 10M\)
- \(Re\) (model scale): \(\sim 25k\)

Aerodynamic design

Floater design
Aerodynamic design
Aerodynamic design

DTU Wind Energy
Department of Wind Energy
Low-Re airfoils and 2D wind tunnel measurements

Figure 3 Measured airfoil characteristics for SD7003 at Reynolds number 30k, 40k, 50k, 60, 100k, 200k. Selig data applied for 100k and 200k.

Figure 5 Applied airfoils for spanwise sections.
Mold for blades

Figure 10 Model scale wind turbine blade (left) and negative mold (right)
Wind generator and hub

6 units, 4x4m, max speed of 1.7 m/s

rpm control, collective blade pitch
Preliminary results
Extreme environment

Setup and validation

Scaling principles
Air velocities (model scale) $\sim 1.5$ m/s
Re (proto scale) $\sim 10$M
Re (model scale): $\sim 25k$

Floater design

Aerodynamic design

Preliminary results
Gentle environment
Floater design

Compact, cost efficient

TLP was chosen – Bachynski (2014) gives input on design considerations

Designed with static model and a WAMIT based dynamic model

Figure 2.4: Floater geometry loaded into WAMIT.
Environmental conditions

Design requirements

max tendon angle with vertical: 10 deg
max tension: $1.8 \times T_0$
min tension: $0.2 \times T_0$

Johannesen et al (2002); Bachynski (2014)
The floater

DTU Wind Energy
Department of Wind Energy
Scaling principles

Air velocities (model scale) $\sim 1.5 \text{ m/s}$
Re (proto scale) $\sim 10M$
Re (model scale): $\sim 25k$

Aerodynamic design

Preliminary results
Extreme environment

Preliminary results
Gentle environment

Setup and validation

Floater design
Wind field in rotor plane

(a) Mean wind speed.

(b) Turbulence intensity.
Rotor thrust

Figure 5.13: Thrust curves for the wind turbine model
Wave climates and RAOs

(a) Sea states 101 - 104

(b) Sea states 105 - 108

(a) Acceleration measured in nacelle and decaying amplitude of linear response.

(b) Power spectrum of acceleration signal.
Preliminary results
Extreme environment

Scaling principles
- Air velocities (model scale) $\sim 1.5 \text{ m/s}$
- $\text{Re (proto scale)} \sim 10\text{M}$
- $\text{Re (model scale)}: \sim 25\text{k}$

Aerodynamic design

Preliminary results
Gentle environment

Setup and validation

Floater design
Preliminary results
Regular, gentle waves

Figure 7.2: Sea state 2
Preliminary results

Irregular waves close to rated wind speed with and without wind
Preliminary results

Irregular waves at close to rated wind speed

![Image of wind turbine and data plots](image)

Figure 7.26: Tower acceleration - Seastate 5 - Wind
Scaling principles

Air velocities
(model scale) ~ 1.5 m/s
(proto scale) ~ 10M
(model scale): ~ 25k

Aerodynamic design

Floater design

Setup and validation

Preliminary results
Extreme environment

Preliminary results
Gentle environment

DTU Wind Energy
Department of Wind Energy

INNOWIND EU
Preliminary results

Response to extreme focused wave

Figure 7.37: Response of structure 1 to focused wave number 8 without wind (S1F08).
Preliminary results

Response to extreme focused wave
Tendon tension

Figure 7.38: Tendon tensions of structure 1 when subjected to focused wave number 8 without wind (S1F08).
Conclusions

Scaling principles
Froude-scaling of water and global aerodynamic loads
Low Re leads to re-designed rotor with larger chord

Aerodynamic design
10 MW rotor scaled to 1:60. Collective pitch and rpm control
2D wind tunnel test at Re down to 30k incorporated in design
Wind generator 4x4 meter max speed of 1.7 m/s

Preliminary results
Extreme environment
Focused waves
Response in platform motion
Spectral analysis

Preliminary results
Gentle environment
Wind effects and rotor effects clearly detectable
Damping effects and RAOs investigated

Setup and validation
Wind field measured in sweeps at 12 levels. TI ~ 6 %
Fairly uniform with slight 'under cut'

Floater design
TLP Ø18m, height 25m, draft 37m
Static and dynamic design considerations
Experimental study of the DTU 10 MW wind turbine on a TLP floater in waves and wind

Henrik Bremose, Robert Mikkelsen, Anders Mandrup Hansen, Robert Laugesen
DTU Wind Energy
hbre@dtu.dk

Nicolai Heilskov, Bjarne Jensen, Jens Kirkegaard
DHI

Part of the INNWIND.EU project
DTU Wind Energy
Department of Wind Energy