# Offshore wind
## Research and possible student projects and opportunities

Michael Muskulus

Department of Civil and Environmental Engineering
Norwegian University of Science and Technology
7491 Trondheim, Norway

Marin Byggteknikkdagen NTNU/PIANC
April 27, 2017

NTNU
Faculty of Engineering
Department of Civil and Environmental Engineering

Why wind energy?

# DAILY WIND POWER NUMBERS

| Daily wind energy | Yesterday's country ranking | Europe's electricity mix | Hourly wind energy generation | Capacity factors |
|---|---|---|---|---|

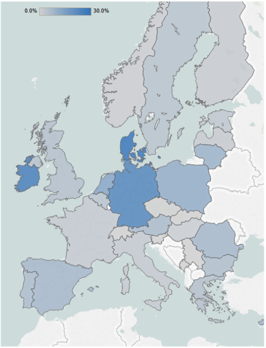
## How much wind was in Europe's electricity yesterday?

Share these figures

Click on countries for national details
Ctrl + click for selecting various countries

24 April 2017

Share of wind energy in total electricity demand




Share of wind energy in electricity demand

**9.2%**

Onshore Wind (GWh)
628
Offshore Wind (GWh)
148

**WHICH COULD POWER**

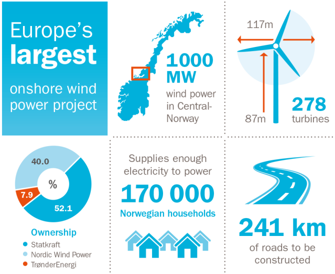
Equivalent EU households *
78 million

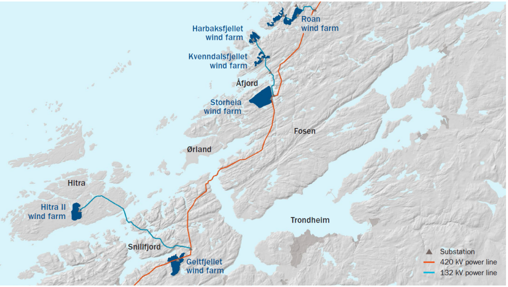
**OR**

Average industrial electricity demand **
27%

* Elaborated on the electricity demand of an average EU28 household in 2015, Eurostats
** Elaborated on the industrial electricity consumption of each EU28 country in 2015, Eurostats

# Wind energy in Norway?




## Characteristics

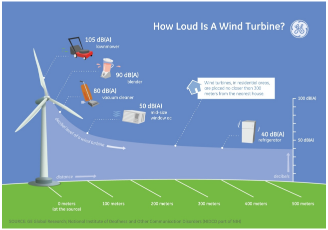
- An important source of electricity (highly efficient as well)
- Carbon-friendly? (e.g. 500 tons CO2 during construction — 500 MWh equivalent)

# Wind energy in Norway?

## Long tradition in Norway

- Fridtjof Nansen 1888 on board the Fram

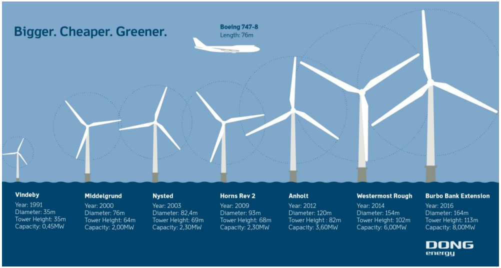
# Why offshore wind energy?




## Issues with onshore wind energy

- Public acceptance (e.g. noise)
- Transportation can be challenging

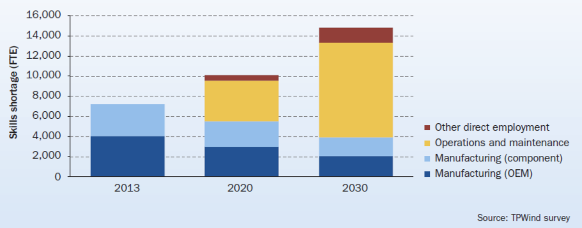
# Why offshore wind energy?




## Wind turbines are growing in size

- Economies of scale: turbines are still growing...
- ... but larger turbines exhibit different dynamics than smaller ones

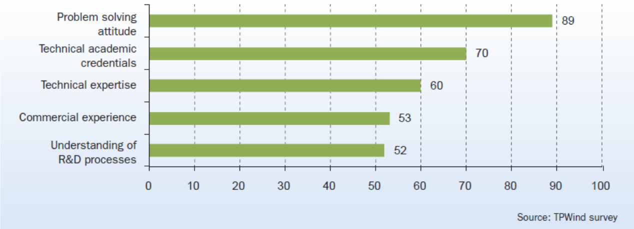
# Why study wind energy?




## The skill shortage in Europe

- A lot of qualified personnel is probably needed in the (future) wind industry
- The EU estimates ca. 1 Million people working in wind energy in 2020
- Worries about finding these people...

# Why study wind energy?

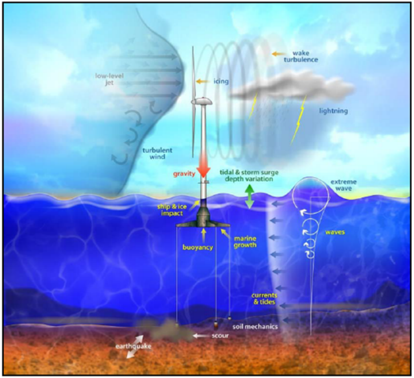



## What skills are employers looking for?

- Most important: Problem solving
- Between practical, technical and industry knowledge: Technical expertise!

# Load simulations

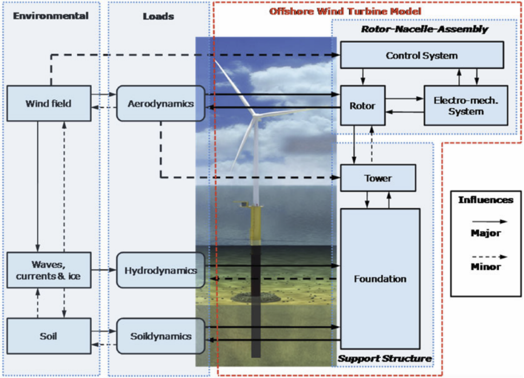
# Load simulations




## Environmental loads

- Behaviour of the wind turbine system governed by response to external loads
- Load simulations assess response in these different environmental conditions

# Load simulations




## Aeroy-hydro-servo-elastic simulations needed

- Simulations have to be done in the time domain (because of nonlinearities)
- Many simple components
- Tight coupling leads to a complex system

# Load simulations

| Design situation | DLC | Wind condition | Waves | Wind and wave directionality | Sea currents | Water level | Other conditions | Type of analysis | Partial safety factor |
|---|---|---|---|---|---|---|---|---|---|
| 1) Power production | 1.1 | NTM $V_{in} < V_{hub} < V_{out}$ RNA | NSS $H_s = E[H_s \| V_{hub}]$ | COD, UNI | NCM | MSL | For extrapolation of extreme loads on the RNA | U | N (1,25) |
| | 1.2 | NTM $V_{in} < V_{hub} < V_{out}$ | NSS Joint prob. distribution of $H_s, T_p, V_{hub}$ | COD, MUL | No currents | NWLR or ≥ MSL | | F | * |
| | 1.3 | ETM $V_{in} < V_{hub} < V_{out}$ | NSS $H_s = E[H_s \| V_{hub}]$ | COD, UNI | NCM | MSL | | U | N |
| | 1.4 | ECD $V_{hub} = V_r - 2$ m/s, $V_r$, $V_r + 2$ m/s | NSS (or NWH) $H_s = E[H_s \| V_{hub}]$ | MIS, wind direction change | NCM | MSL | | U | N |
| | 1.5 | EWS $V_{in} < V_{hub} < V_{out}$ | NSS (or NWH) $H_s = E[H_s \| V_{hub}]$ | COD, UNI | NCM | MSL | | U | N |
| | 1.6a | NTM $V_{in} < V_{hub} < V_{out}$ | SSS $H_s = H_{s,SSS}$ | COD, UNI | NCM | NWLR | | U | N |
| | 1.6b | NTM $V_{in} < V_{hub} < V_{out}$ | SWH $H = H_{SWH}$ | COD, UNI | NCM | NWLR | | U | N |

## Many loadcases need to be assessed

- Fatigue loads need to be assessed for the design lifetime (e.g. 25-30 years)
- Ultimate loads need to be estimated (e.g. 50 year return period) from responses

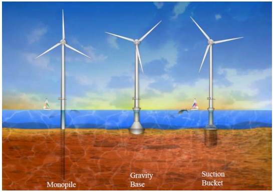
# Load simulations

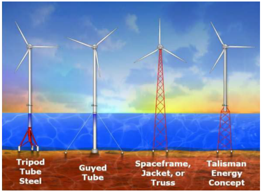
| Design situation | DLC | Wind condition | Waves | Wind and wave directionality | Sea currents | Water level | Other conditions | Type of analysis | Partial safety factor |
|---|---|---|---|---|---|---|---|---|---|
| 4) Normal shut down | 4.1 | NWP $V_{in} < V_{hub} < V_{out}$ | NSS (or NWH) $H_s = E[H_s \| V_{hub}]$ | COD, UNI | No currents | NWLR or ≥ MSL | | F | * |
| | 4.2 | EOG $V_{hub} = V_r \pm 2$m/s and $V_{out}$ | NSS (or NWH) $H_s = E[H_s \| V_{hub}]$ | COD, UNI | NCM | MSL | | U | N |
| 5) Emergency shut down | 5.1 | NTM $V_{hub} = V_r \pm 2$m/s and $V_{out}$ | NSS $H_s = E[H_s \| V_{hub}]$ | COD, UNI | NCM | MSL | | U | N |
| 6) Parked (standing still or idling) | 6.1a | EWM Turbulent wind model $V_{hub} = k_1 V_{ref}$ | ESS $H_s = k_2 H_{s50}$ | MIS, MUL | ECM | EWLR | | U | N |
| | 6.1b | EWM Steady wind model $V(z_{hub}) = V_{e50}$ | RWH $H = H_{red50}$ | MIS, MUL | ECM | EWLR | | U | N |
| | 6.1c | RWM Steady wind model $V(z_{hub}) = V_{red50}$ | EWH $H = H_{50}$ | MIS, MUL | ECM | EWLR | | U | N |
| | 6.2a | EWM Turbulent wind model $V_{hub} = k_1 V_{ref}$ | ESS $H_s = k_2 H_{s50}$ | MIS, MUL | ECM | EWLR | Loss of electrical network | U | A |
| | 6.2b | EWM Steady wind model $V(z_{hub}) = V_{e50}$ | RWH $H = H_{red50}$ | MIS, MUL | ECM | EWLR | Loss of electrical network | U | A |
| | 6.3a | EWM Turbulent wind model $V_{hub} = k_1 V_1$ | ESS $H_s = k_2 H_{s1}$ | MIS, MUL | ECM | NWLR | Extreme yaw misalignment | U | N |
| | 6.3b | EWM Steady wind model $V(z_{hub}) = V_{e1}$ | RWH $H = H_{red1}$ | MIS, MUL | ECM | NWLR | Extreme yaw misalignment | U | N |
| | 6.4 | NTM $V_{hub} < 0{,}7\ V_{ref}$ | NSS Joint prob. distribution of $H_s, T_p, V_{hub}$ | COD, MUL | No currents | NWLR or ≥ MSL | | F | * |

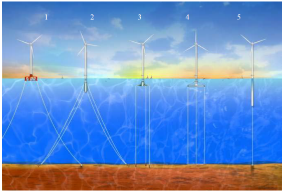
## Many loadcases need to be assessed

- Many variabels need to be varied (e.g. directionality)
- Loadcase table typically with 1700+ entries

# Support stucture concepts




## Issues

- Different concepts result in different challenges
- Not always clear which concept is best for a given site
- Still new ideas possible... (also re-evaluation due to turbine size growth)

DEMONSTRATION

# Current research

**AWESOME** Advanced Wind Energy Systems Operation and Maintenance Expertise

ForWind, DTU, RAMBOLL, TUM, DONG energy, enel, circe, ALSTOM, DNV·GL, University of Strathclyde Glasgow, UCLM, Loughborough University

**ABYSS** Advanced BeYond Shallow waterS – Optimal design of offshore wind turbine support structures

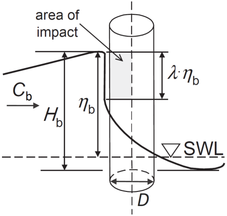
DTU, DONG energy, Aalborg University Denmark, Universal Foundation, SINTEF, Dassault Systèmes

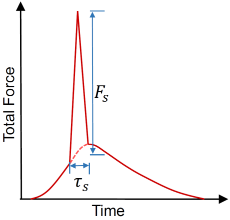
**NOWITECH** Norwegian Research Centre for Offshore Wind Technology

FME Centre for Environment-friendly Energy Research

# Breaking wave loads

# Breaking wave loads

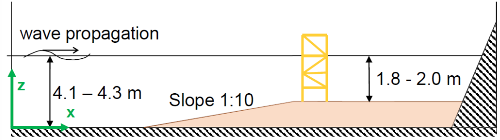



## The problem

- Plunging breakers can lead to very large impact (slamming) forces
- Risk for installations in shallow waters
- How often do such extreme events occur?
- How large are the forces?

# Breaking wave loads

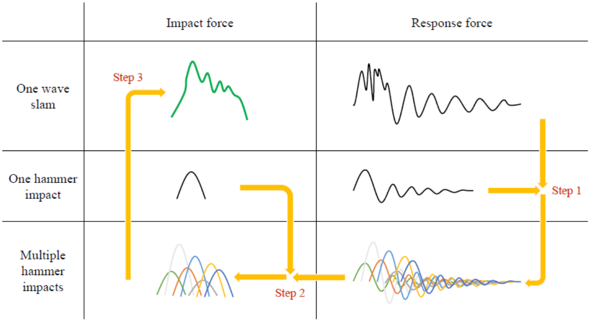




## The WaveSlam project

- Experimental campaign at Forschungszentrum Küste (Hannover) 2013
- Scaled jacket with force transducers

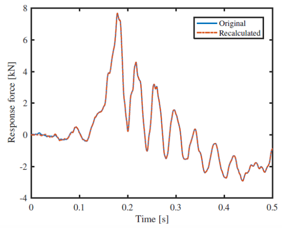
# Breaking wave loads

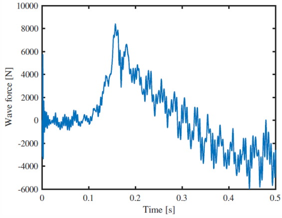


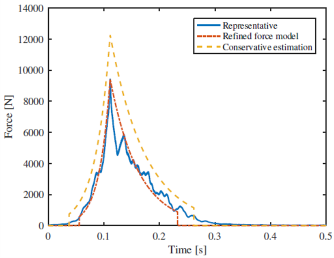

## Force estimation

- Uses linearity of the system
- Hammer tests used as substitute for impulse-response functions
- Least-squares solution

# Breaking wave loads



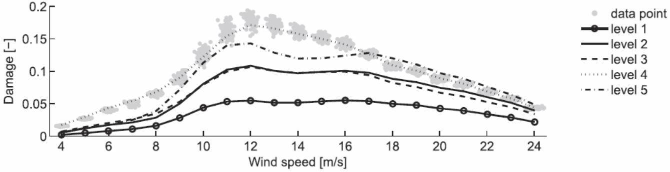




## Results

- Accurate force reconstruction possible
- Novel force model recently proposed

# Simplified fatigue load assessment

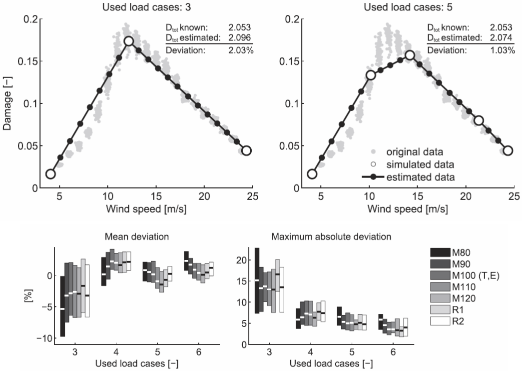
# Simplified fatigue load assessment




## The problem

- Fatigue assessment of wind turbines amounts to 1700+ loadcases (60 min duration)
- Damage needs to be assessed in each joint of the structure
- Simulations typically slower than realtime
- Can we reduce the number of analyses?

# Simplified fatigue load assessment

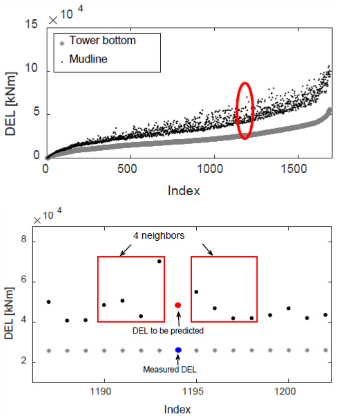


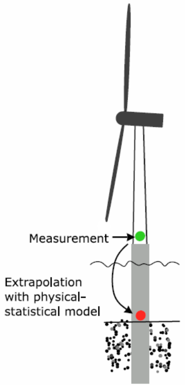

## Piecewise-linear regression (Zwick et al. 2015)

- Idea: parameterize shape of damage curve
- Here for mean wind speed, but possible for other parameters as well
- Accuracy of 5 percent for 4 of 21 loadcases

# Remaining useful life

# Extrapolating loads



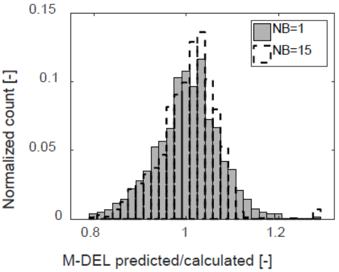




**How to extrapolate fatigue damage from measurements at a different location?)**

- Tower bottom damage equivalent loads (DELs) measured
- Mudline DEL predicted by nearest-neighbour regression

# Extrapolating loads

| Case | Method | Variance Ratio DEL [-] | Ratio $DEL_L$ [-] | Ratio Damage [-] |
|---|---|---|---|---|
| **Design** | M | 0.07 | 1.02 | 1.08 |
| | W | 0.06 | 1.00 | 0.99 |
| **Design with $v_w$ bin** | M | 0.01 | 0.99 | 0.97 |
| | W | 0.01 | 1.00 | 0.99 |
| **Extended** | M | 0.02 | 1.03 | 1.09 |
| | W | 0.02 | 0.99 | 0.97 |
| **Extended with $v_w$ bin** | M | 0.05 | 0.98 | 0.94 |
| | W | 0.08 | 0.99 | 0.97 |




## Accuracy of this simple method

- Fatigue damage predicted within 1 percent for design cases
- Prediction within 3 percent for cases with different turbulence intensity (extended)

# Research skills and topics

## What do these research projects have in common?

- Good understanding of structural dynamics necessary
- Computationally expensive
- Need to consider and understand uncertainties (probability, risk)
- Need basic knowledge of statistics
- Typically novel, custom-made solutions (programming!)
- Applying state of the art data analysis (machine learning, time series analysis, Bayesian decision theory)
- Trying to reduce the cost of energy

# Student projects

DR. TECHN. OLAV OLSEN

Fraunhofer IWES

OWEC TOWER AS

RAMBØLL

SENVION wind energy solutions

Keppel

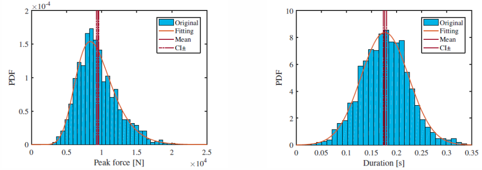
Fedem Technology

SIEMENS Siemens Wind Power

Statkraft

SINTEF

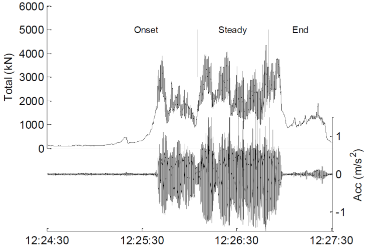
# Project: Improving breaking wave models




## Description

- On-going analysis of the data from the Waveslam project
- Can we predict the slamming force for a given seastate?

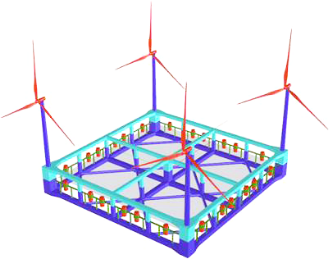
# Project: Ice loads on offshore wind turbines




## Description

- Pori 1: First Finnish offshore wind farm in Gulf of Bothnia (2010–)
- Possibility of very high fatigue damage due to frequency lock-in ice interaction
- Can we predict the risk for such extreme events?

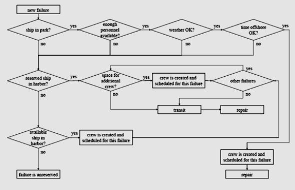
# Project: Multi-rotor floater



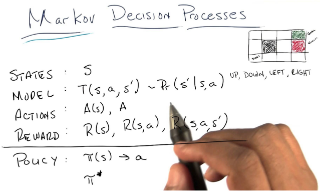
## Description

- How to design a floating multi-rotor wind turbine?
- Especially, how does the presence of multiple turbines influence the fatigue damage?
- And what about the design of the mooring system?

# Project: Strategies for maintenance optimization under uncertainty



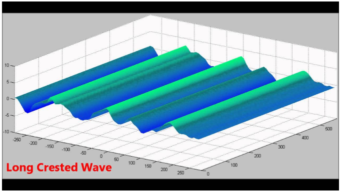


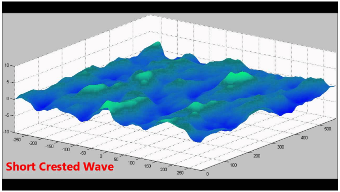



## Description

- Work with an existing simulation model for the operational phase of a wind farm
- Implement and test new strategies: how should repairs be scheduled?

# Project: Influence of directional wave spreading

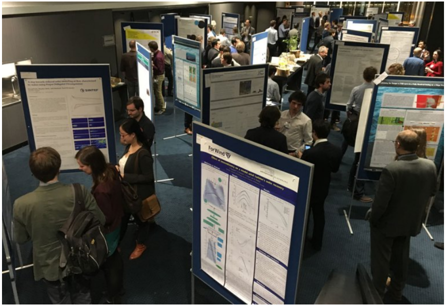



## Description

- Load simulations typically use long-crested waves... but real waves are short-crested
- What are the implications for the design of offshore wind turbines?

# Yearly conference



## EERA Deep Sea Offshore Wind R&D Conference (DeepWind)

- Students with interesting results can attend the conference
- Contributions published in Energy Procedia / IOP Conference series
- More information: `https://www.sintef.no/projectweb/eera-deepwind2017/`

# Questions?