Cost-optimized design of tubular steel towers and offshore support structures

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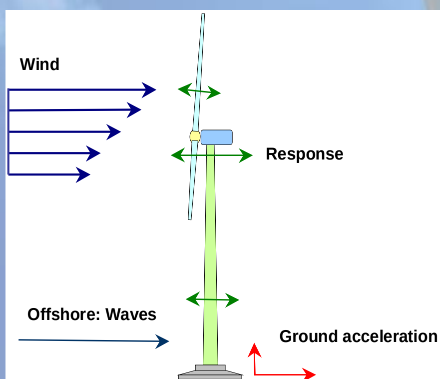
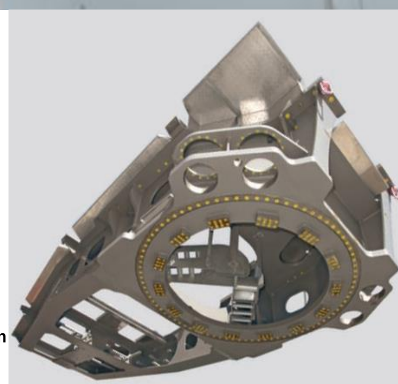
1. Windrad Engineering and LWET
2. Tall towers and costs of wind turbines
3. Tower optimization software
4. Example for application
5. Monopile Foundation for OWEC

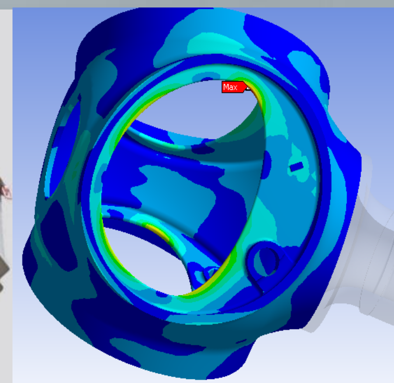
Windrad Engineering GmbH

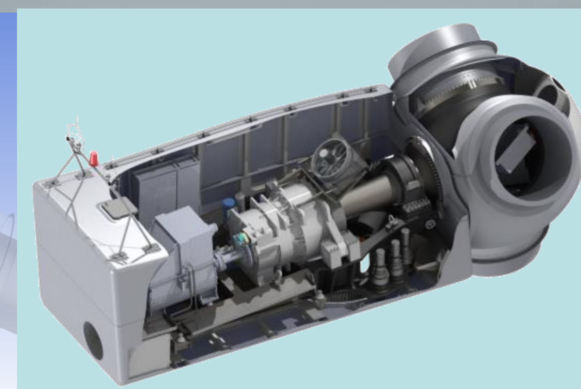
Engineering Consultant for wind industry since 2002

Design of wind turbines (onshore and offshore)



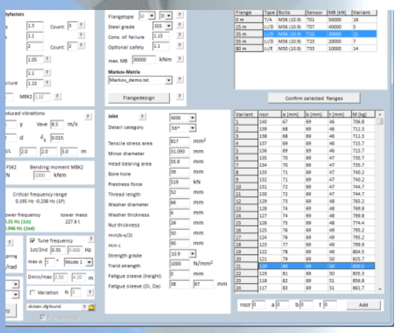






Training

Software



Measurements

1. Windrad Engineering GmbH und LWET

windrad simulation & engineering

久和能源 Geoho Energy

Xian Geoho Energy Technology Co., Ltd

Geoho 2.0 MW

Rated power : 2.0 MW

Rotor diameters : 87 m, 93 m, 100 m

Gearbox, high-speed generator, 3-point bearing

With Mita and many Chinese suppliers

Status: Series production

Geoho 2.1 MW and 113 m rotor diameter

Prototype 2014

LWET

Stiftungslehrstuhl Windenergietechnik

MSF Universität Rostock Albert-Einstein-Straße 2 18059 Rostock

Endowed Chair of Wind Energy Technology at the University of Rostock

Funded by Nordex SE (Manufacturer of wind turbines), started 2014

Research on various topics related to wind turbines

- Improvement of simulation and computational methods
- Mass and cost optimization of structures

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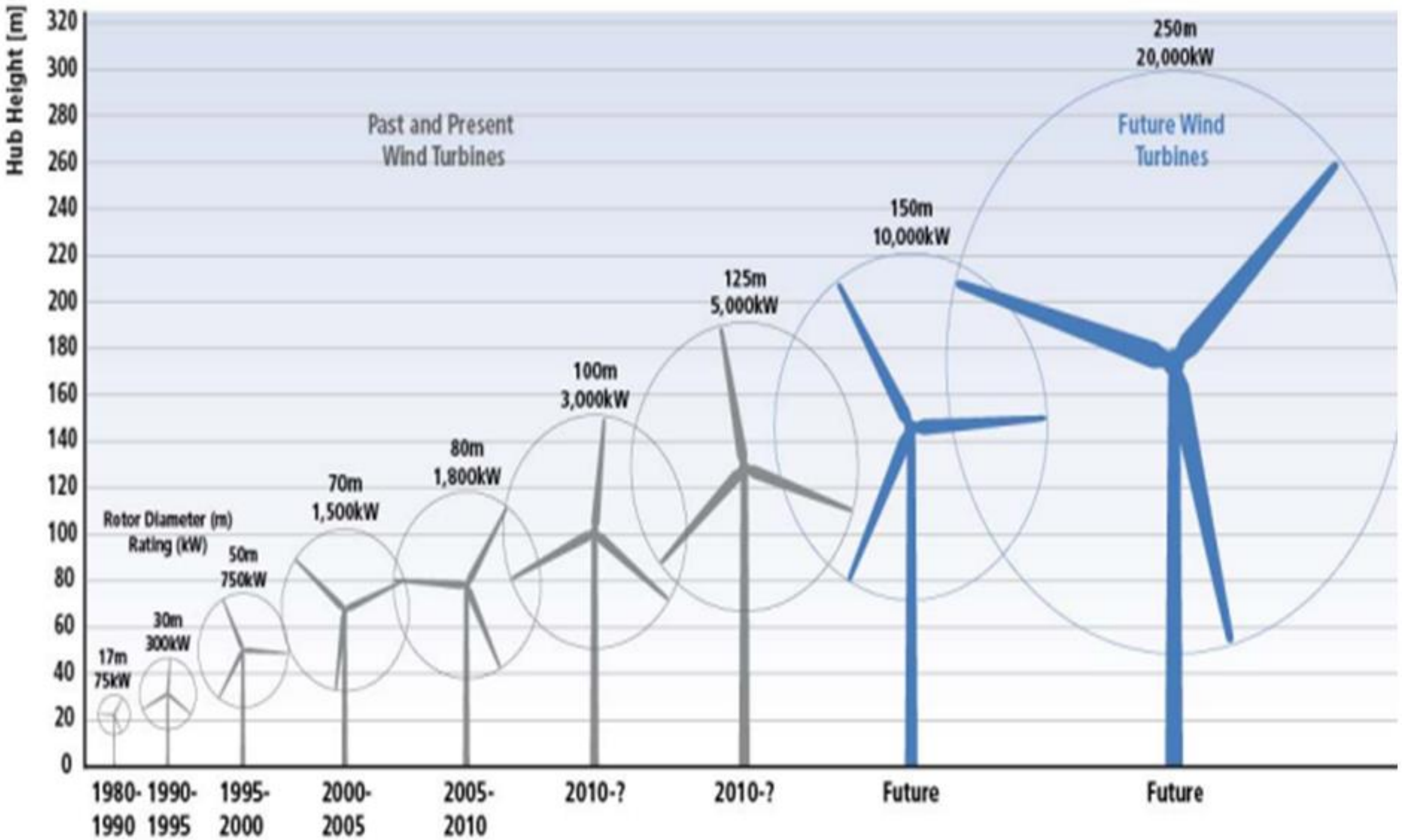
2. Motivation for taller towers

Technical Advancements: For instance growth in size of typical commercial wind turbines.



(from the IPCC April 2012 report on mitigating climate change)

Wind farm Palm Springs in USA

Current situation (2014)

- Wind turbines in the 2 to 3 MW class
- Rotor diamters 100 m to 120 m
- Hub heights for class 3 sites (< 7.5 m/s) up to 140 m

Example Nordex N117

- 117 m rotor
- 2.4 MW rated power
- Hub heights 91 m and 141 m

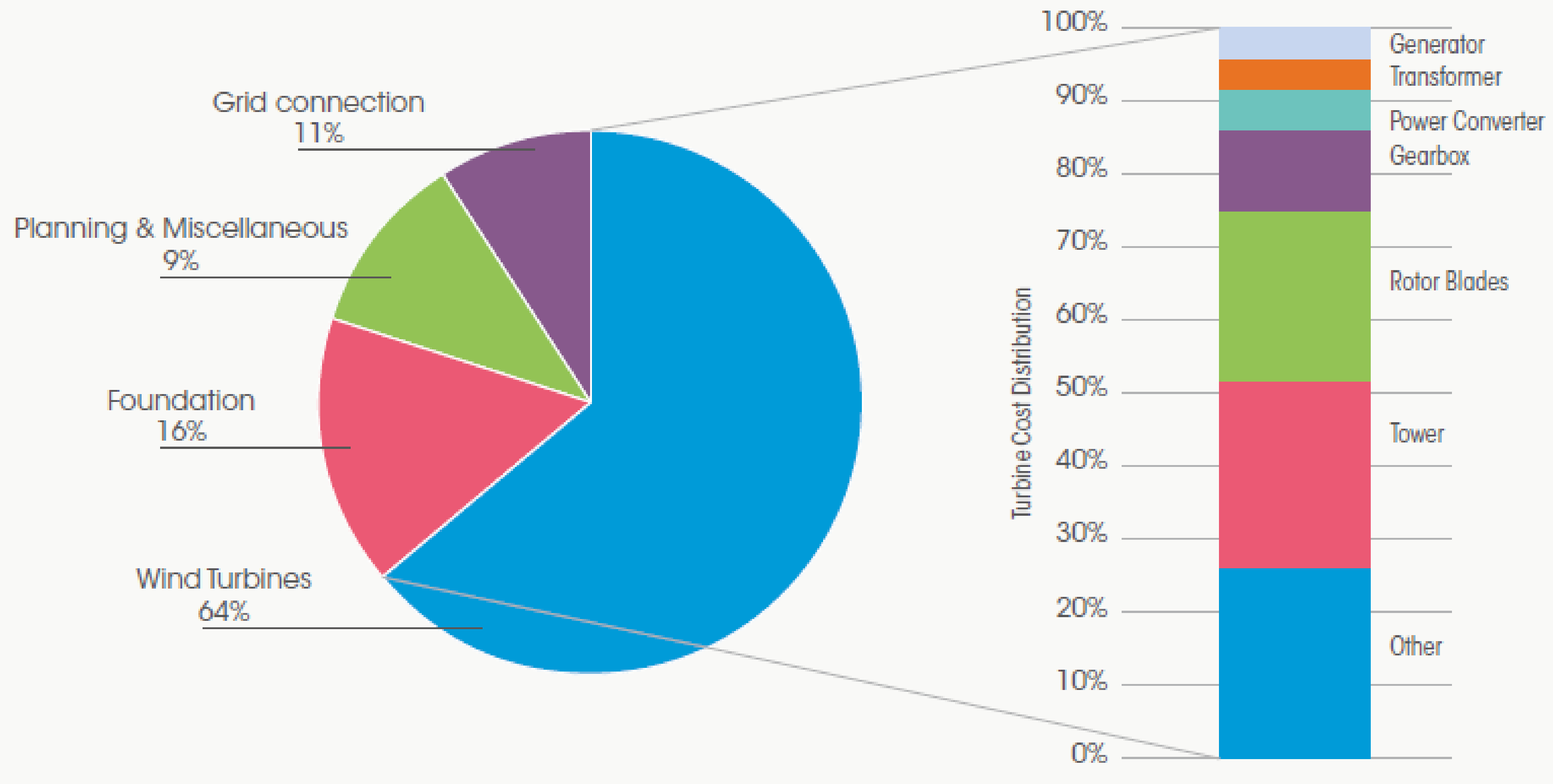
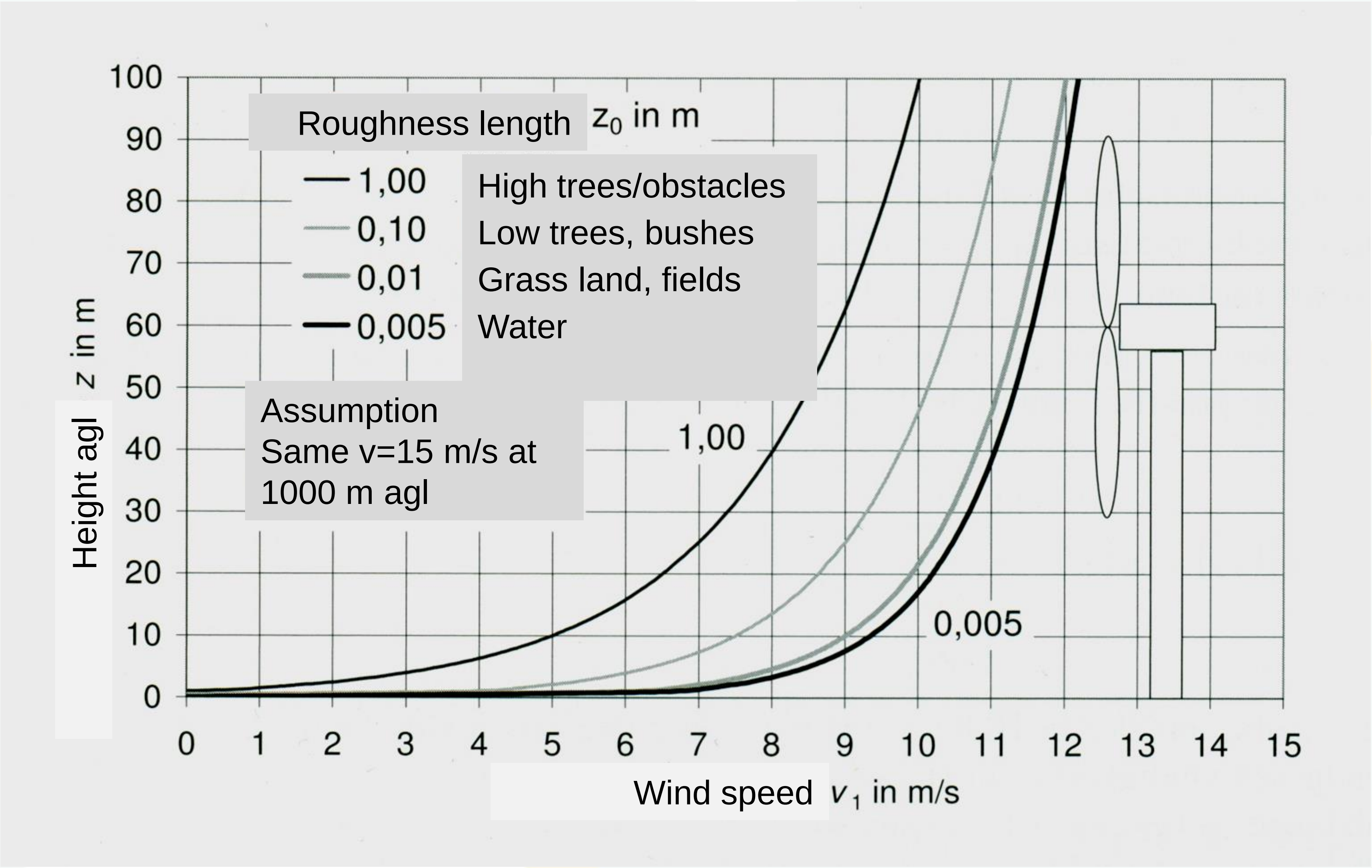


FIGURE 4.1: CAPITAL COST BREAKDOWN FOR A TYPICAL ONSHORE WIND POWER SYSTEM AND TURBINE

Source: Blanco, 2009.


Roughness length z0 in m
1,00 High trees/obstacles
0,10 Low trees, bushes
0,01 Grass land, fields
0,005 Water
Assumption
Same v=15 m/s at
1000 m agl
1,00
0,005
Height agl z in m
100
90
80
70
60
50
40
30
20
10
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Wind speed v1 in m/s

Surface roughness

The higher the roughness

- the lower the wind speed
- the higher the turbulence

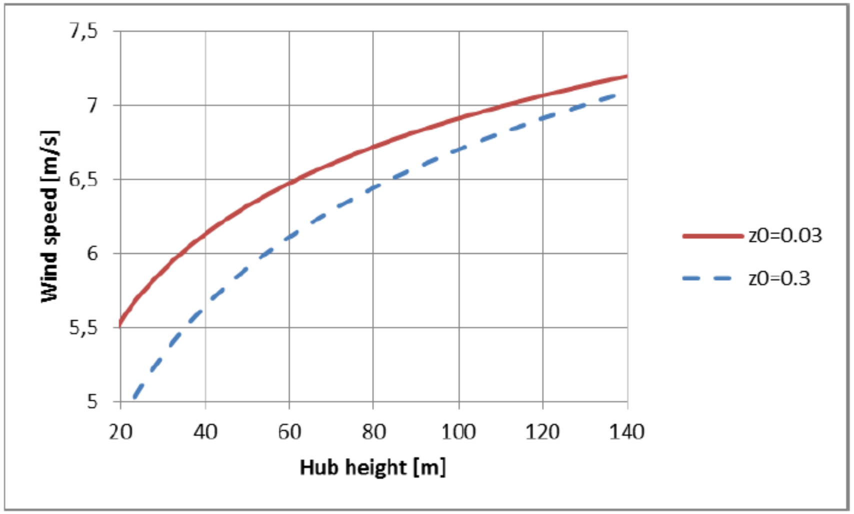
Influence of surface up to about 1000 m

Both windshear and turbulence are unfavorable for wind turbines

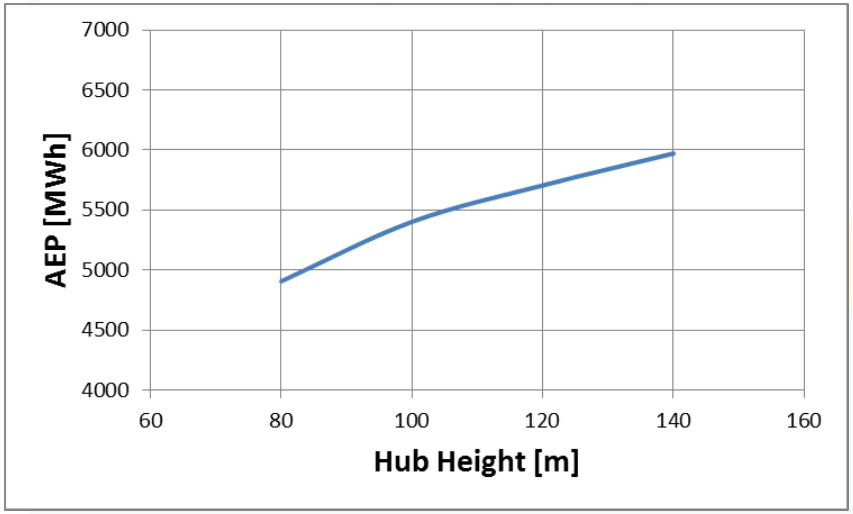
Consequences

Taller tower	higher wind speed	higher AEP
Taller tower	lower turbulence	lower loading of turbine

Wind speed variation



AEP: Annual energy production / $z_0 = 0.3$



From 80 m to 120 m:
AEP + 780 MWh / year

From 80 m to 140 m:
AEP + 1070 MWh / year

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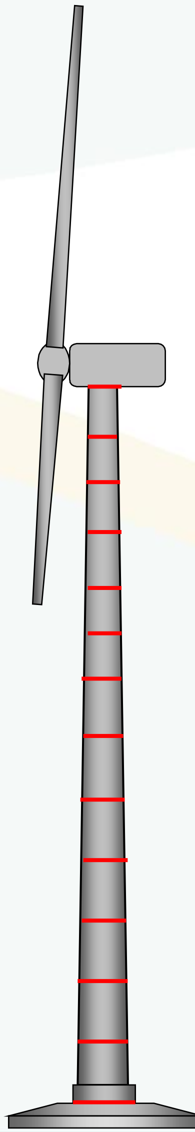
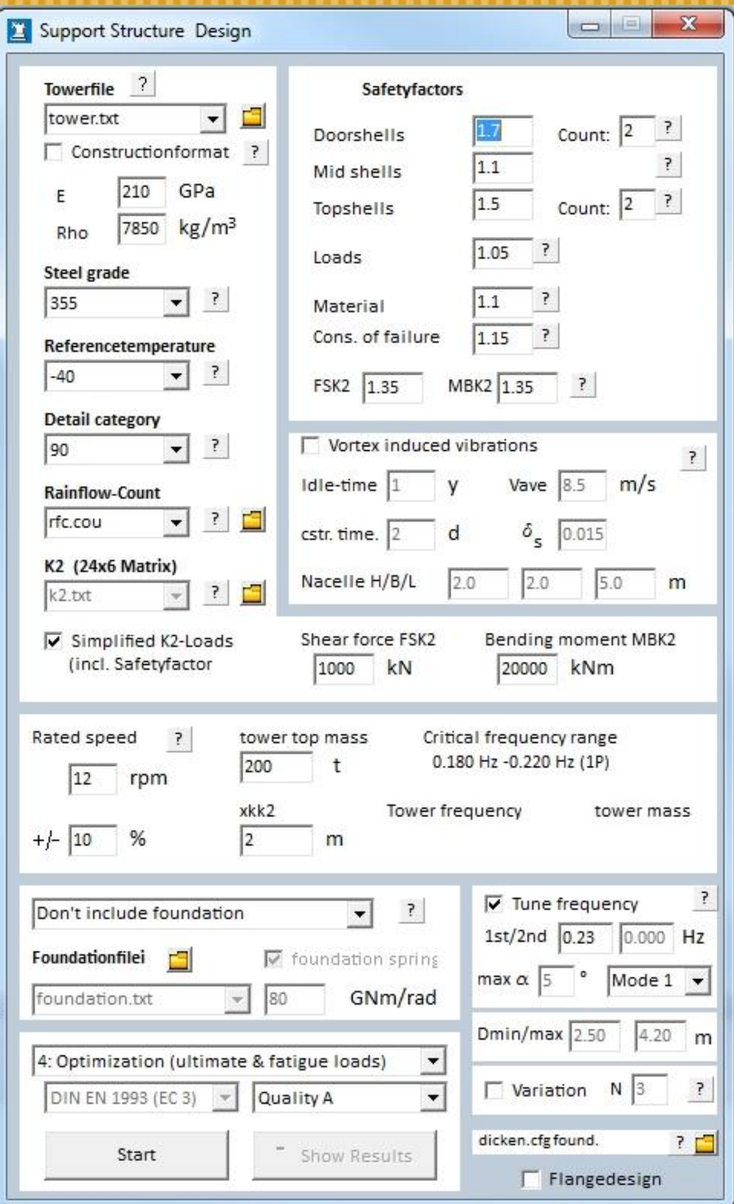
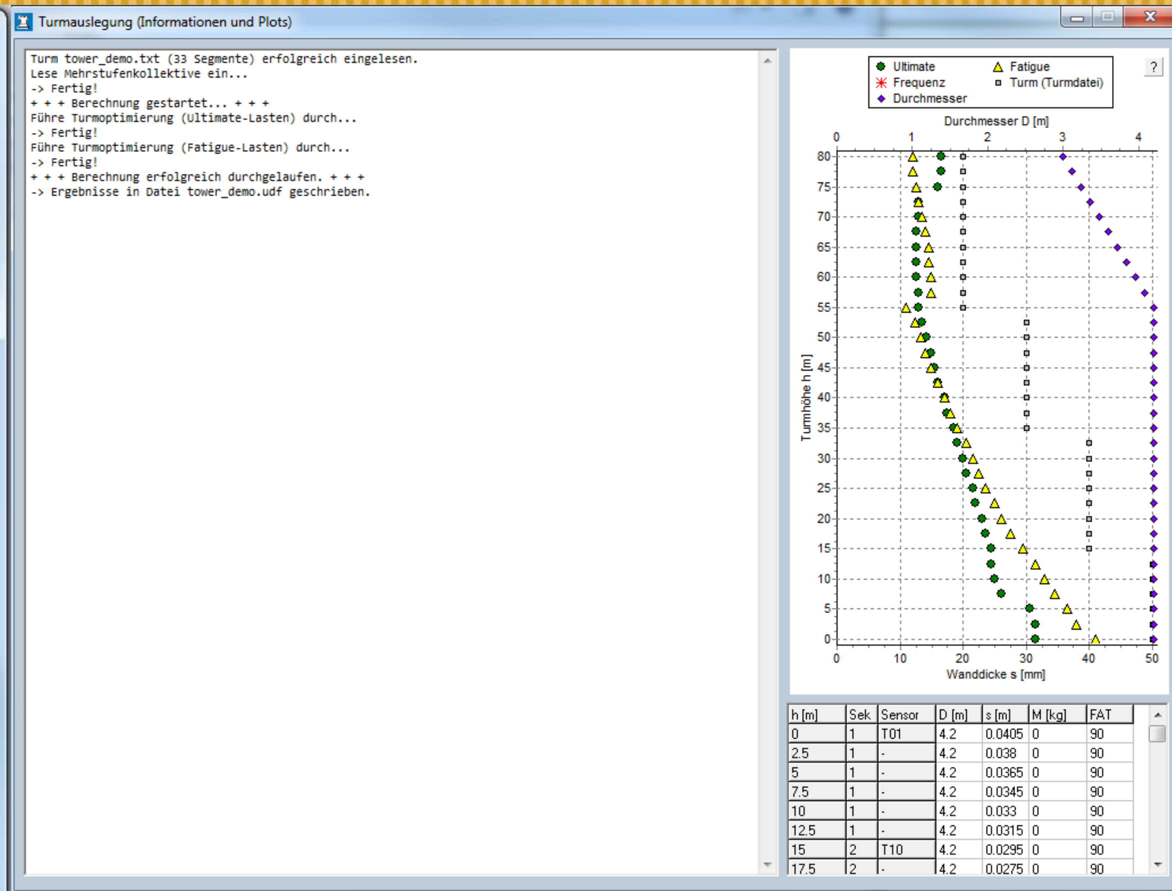
- Software for design of towers
  - Optimized wall thicknesses of **tower shells** and optimized **flanges** depending on given loads (Extreme, Fatigue)
  - Tuning of 1^{st} and 2^{nd} tower frequency
  - All calculations according to **EC3** and thus consistent with latest guidelines
- Comfortable handling
  - User interface offers easy selection of steel type (S355, S275, …), FAT-Class (90, 80, …), bolts (M42, M36, …) and so on
- Fast calculation
  - Optimized tower design within seconds
  - Detailed information about required analyses (Buckling of shells, Damage on welded seams, vortex induced vibrations, …)

- Extreme-Loads at Towertop or sectional loads
  - Simplified: Only extreme shear force and bending moment
  - Or detailed loads: simultaneous loads Fx, Fy, Fz, Mx, My, Mz
- Fatigue-Loads at welded seams
  - Load spectra bending moments My, Mz
  - Optional interpolation
- For design of flanges
  - Extreme bending moments and Markov-Matrices at flange positions
- For estimation of Eigenfrequencies
  - Mass and offset of Towertop
  - Foundation stiffness
- Further parameters of the design scenario
  - Tower geometry (diameters, shell heights), Steel type, FAT-Class, Reference temperature, Safety Factors, bolt types, …




Support Structure Design
Towerfile
tower.txt
Constructionformat
E 210 GPa
Rho 7850 kg/m³
Steel grade
355
Referencetemperature
-40
Detail category
90
Rainflow-Count
rfc.cou
K2 (24x6 Matrix)
k2.txt
Safetyfactors
Doorshells 1.7 Count: 2
Mid shells 1.1
Topshells 1.5 Count: 2
Loads 1.05
Material 1.1
Cons. of failure 1.15
FSK2 1.35 MBK2 1.35
Vortex induced vibrations
Idle-time 1 y Vave 8.5 m/s
cstr. time. 2 d δs 0.015
Nacelle H/B/L 2.0 2.0 5.0 m
Simplified K2-Loads (incl. Safetyfactor
Shear force FSK2 1000 kN
Bending moment MBK2 20000 kNm
Rated speed 12 rpm
+/- 10 %
tower top mass 200 t
xkk2 2 m
Critical frequency range
0.180 Hz -0.220 Hz (1P)
Tower frequency
tower mass
Don't include foundation
Foundationfilei
foundation spring
foundation.txt 80 GNm/rad
Tune frequency
1st/2nd 0.23 0.000 Hz
max α 5 ° Mode 1
Dmin/max 2.50 4.20 m
Variation N 3
dicken.cfg found.
Flangedesign
4: Optimization (ultimate & fatigue loads)
DIN EN 1993 (EC 3)
Quality A
Start
Show Results


Turmauslegung (Informationen und Plots)
Turm tower_demo.txt (33 Segmente) erfolgreich eingelesen.
Lese Mehrstufenkollektive ein...
-> Fertig!
+ + + Berechnung gestartet... + + +
Führe Turmoptimierung (Ultimate-Lasten) durch...
-> Fertig!
Führe Turmoptimierung (Fatigue-Lasten) durch...
-> Fertig!
+ + + Berechnung erfolgreich durchgelaufen. + + +
-> Ergebnisse in Datei tower_demo.udf geschrieben.
Ultimate
Fatigue
Frequenz
Turm (Turmdatei)
Durchmesser
Durchmesser D [m]
Turmhöhe h [m]
Wanddicke s [mm]
h [m] Sek Sensor D [m] s [m] M [kg] FAT
0 1 T01 4.2 0.0405 0 90
2.5 1 - 4.2 0.038 0 90
5 1 - 4.2 0.0365 0 90
7.5 1 - 4.2 0.0345 0 90
10 1 - 4.2 0.033 0 90
12.5 1 - 4.2 0.0315 0 90
15 2 T10 4.2 0.0295 0 90
17.5 2 - 4.2 0.0275 0 90

Flangetype	Li / D	?
Steel grade	355	?
Cons. of failure	1.15	?
Optional safety	1.1	?
max. MB	30000 kNm	?

Markov-Matrix

Markov_demo.txt ?

Flangedesign ?

Flange	Type	Bolts	Sensor	MB [kN]	Variant
0 m	T/A	M36 (10.9)	T01	50000	4
15 m	Li/D	M36 (10.9)	T07	40000	6
35 m	Li/D	M36 (10.9)	T15	30000	21
55 m	Li/D	M36 (10.9)	T23	20000	9
80 m	Li/E	M30 (10.9)	T33	10000	28

Confirm selected flanges

Joint ?

Joint	M36	
Detail category	36*	
Tensile stress area	817	mm^2
Minor diameter	31.093	mm
Head bearing area	55.9	mm
Bore hole	39	mm
Prestress force	519	kN
Thread length	52	mm
Washer diameter	66	mm
Washer thickness	6	mm
Nut thickness	29	mm
min(b-s/2)	50	mm
min c	90	mm
Strength grade	10.9	
Yield strength	1000	N/mm^2
Fatigue sleeve (height)	0	mm
Fatigue sleeve (Di, Da)	38, 67	mm

Variant	nscr	a [mm]	b [mm]	t [mm]	M [kg]
2	139	68	69	46	711.3
3	138	68	69	46	711.3
4	137	69	69	46	715.7
5	136	69	69	46	715.7
6	135	70	69	47	735.7
7	134	70	69	47	735.7
8	133	71	69	47	740.2
9	132	71	69	47	740.2
10	131	72	69	47	744.7
11	130	72	69	47	744.7
12	129	73	69	48	765.2
13	128	74	69	48	769.8
14	127	74	69	48	769.8
15	126	75	69	48	774.4
16	125	76	69	49	795.2
17	124	76	69	49	795.2
18	123	77	69	49	799.9
19	122	78	69	49	804.5
20	121	79	69	50	825.7
21	120	80	69	50	830.5
22	119	81	69	50	835.3
23	118	82	69	51	856.8
24	117	83	69	51	861.7
25	116	84	69	51	866.5

nscr 0 a 0 b 0 t 0 Add

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Strategies for the tower design.

Strategy 1: The tower satisfies normal transport restrictions (maximum base diameter 4.2 m) and the lowest tower frequency sufficiently above the rotor frequency

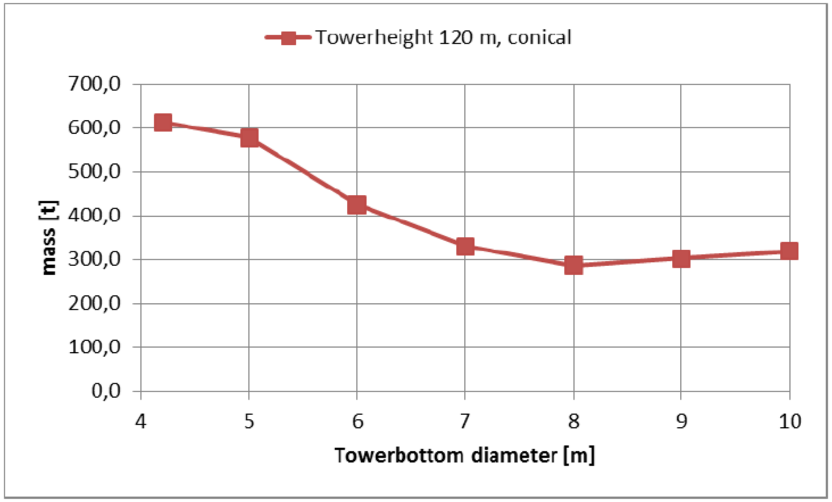
Strategy 2: Base diameter below transport limit but frequency condition is given up

Strategy 3: Frequency condition is kept but transport limit is given up

Example: 2 MW / 90 m wind turbine

Hub height [m]	Strategy	Tower mass [t]	1. freq. [HZ]	2. freq. [Hz]
80	1	144	0.35	3.10
120	1	612	0.30	1.39
120	2	298	0.21	1.36
120	3	287	0.31	1.80

Properties of towers for different hub heights and design strategies



Mass of conical towers with different base diameters

From 80 m to 120 m:

AEP + 780 MWh /year

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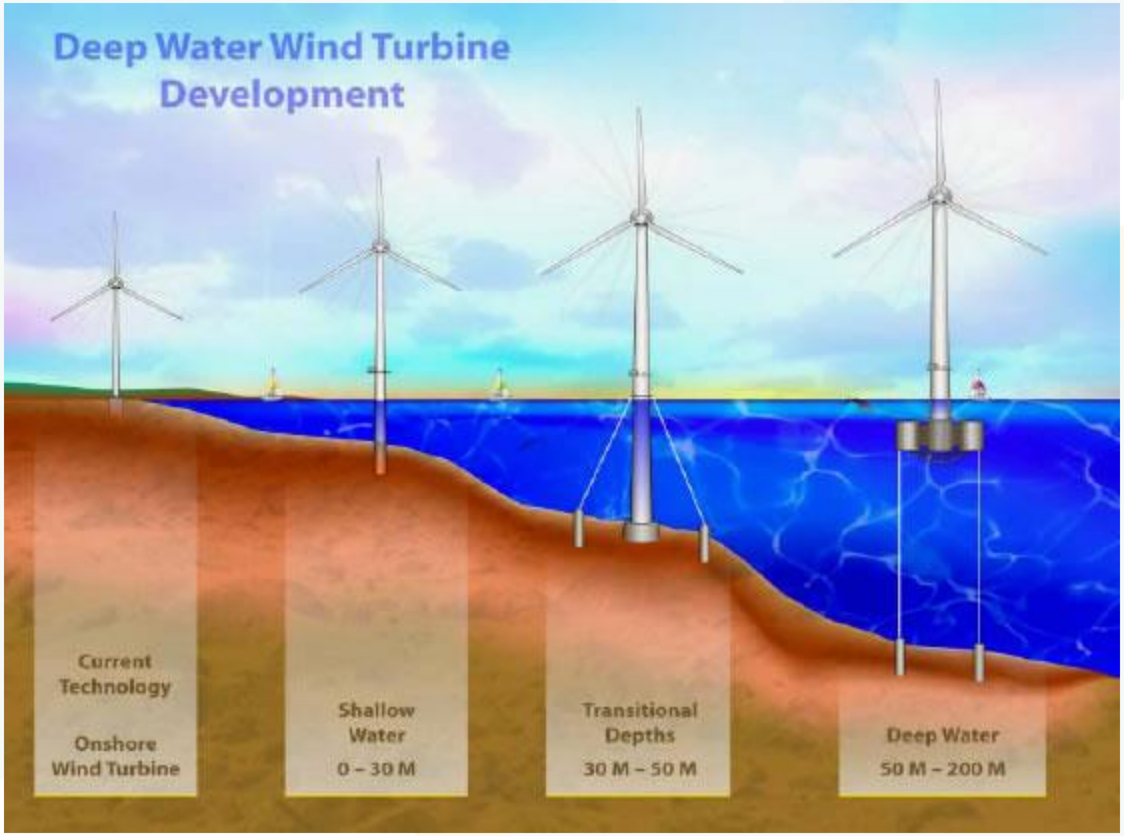
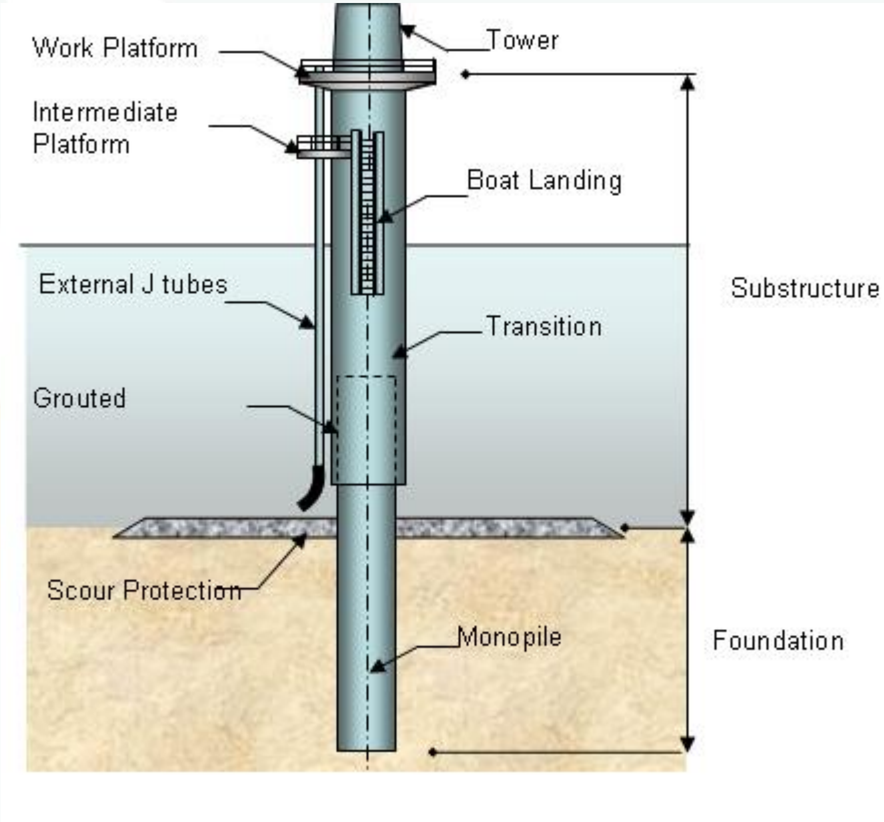

Deep Water Wind Turbine
Development
Current
Technology
Onshore
Wind Turbine
Shallow
Water
0 – 30 M
Transitional
Depths
30 M – 50 M
Deep Water
50 M – 200 M

Substructure and foundation for OWEC

- Monopile (in seabed)
- Transition piece
- Tower



Normally foundation and tower are treated separately

Extension of tower software

Treats complete substructure and foundation including properties of seabed interaction between monopile and seabed

Optimization of substructures for planned offshore wind farm

Conclusions

- Motivation for taller towers: higher AEP and lower loading
- Tower design software introduced
- Example given for tubular tower design
- Extension to monopiles

Extension to hybrid towers (concrete/steel) in progress

Thank you for your attention!