Dogger Bank Reference Wind Power Plant: Layout, Electrical Design, and Wind Turbine Specification

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Dogger Bank wind power plant

Merz KO. Turbine placement in the NOWITECH Reference Windfarm. Memo AN 14.12.09, SINTEF Energy Research, 2014.

Kirkeby H. NOWITECH Reference Windfarm electrical design. Memo AN 14.12.15, SINTEF Energy Research, 2014.

Brantsæter H, Årdal AR. Dogger Bank Reference Windfarm AC design. Memo AN 14.12.42, SINTEF Energy Research, 2014.

Direct-drive 10 MW wind turbine

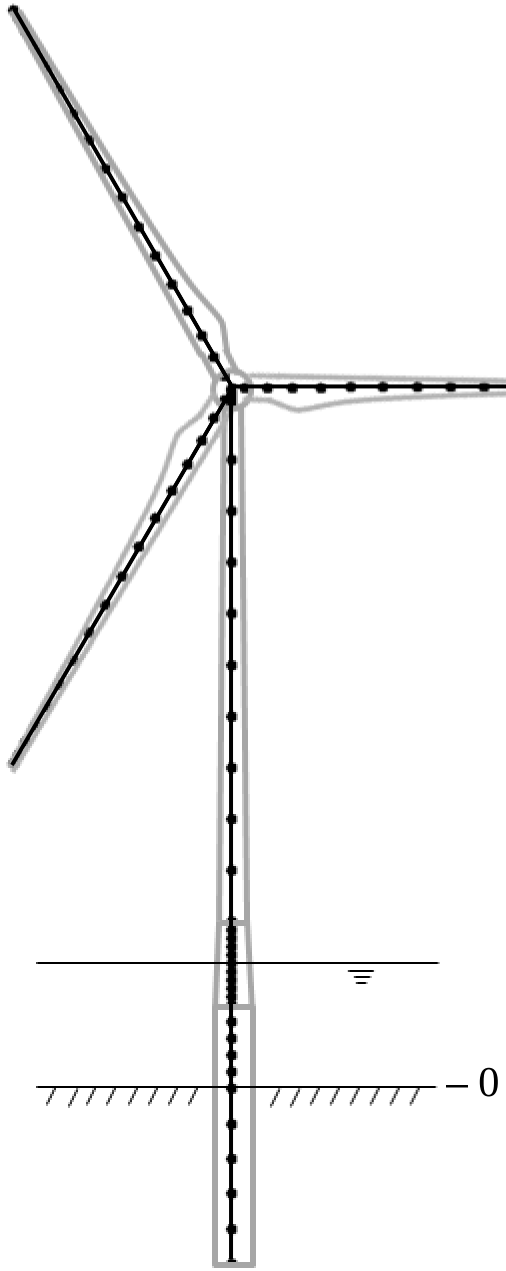
Bak C, *et al*. Description of the DTU 10 MW Reference Wind Turbine. DTU Wind Energy Report-I-0092, 2013.

Hansen MH, Henriksen LC. Basic DTU Wind Energy Controller. DTU Wind Energy Report E-0028, 2013.

Merz KO. Pitch actuator and generator models for wind turbine control system studies. Memo AN 15.12.35, SINTEF Energy Research, 2015.

Merz KO. Design verification of the drivetrain, support structure, and controller for a direct-drive version of the DTU 10 MW Reference Wind Turbine. Memo AN 15.12.68, SINTEF Energy Research, 2015.

DTU 10 MW wind turbine (+ NOWITECH 10 MW nacelle), offshore foundation



Tower +40 to +145 m
Stiffened w.r.t. onshore design
approx. 900 tonnes

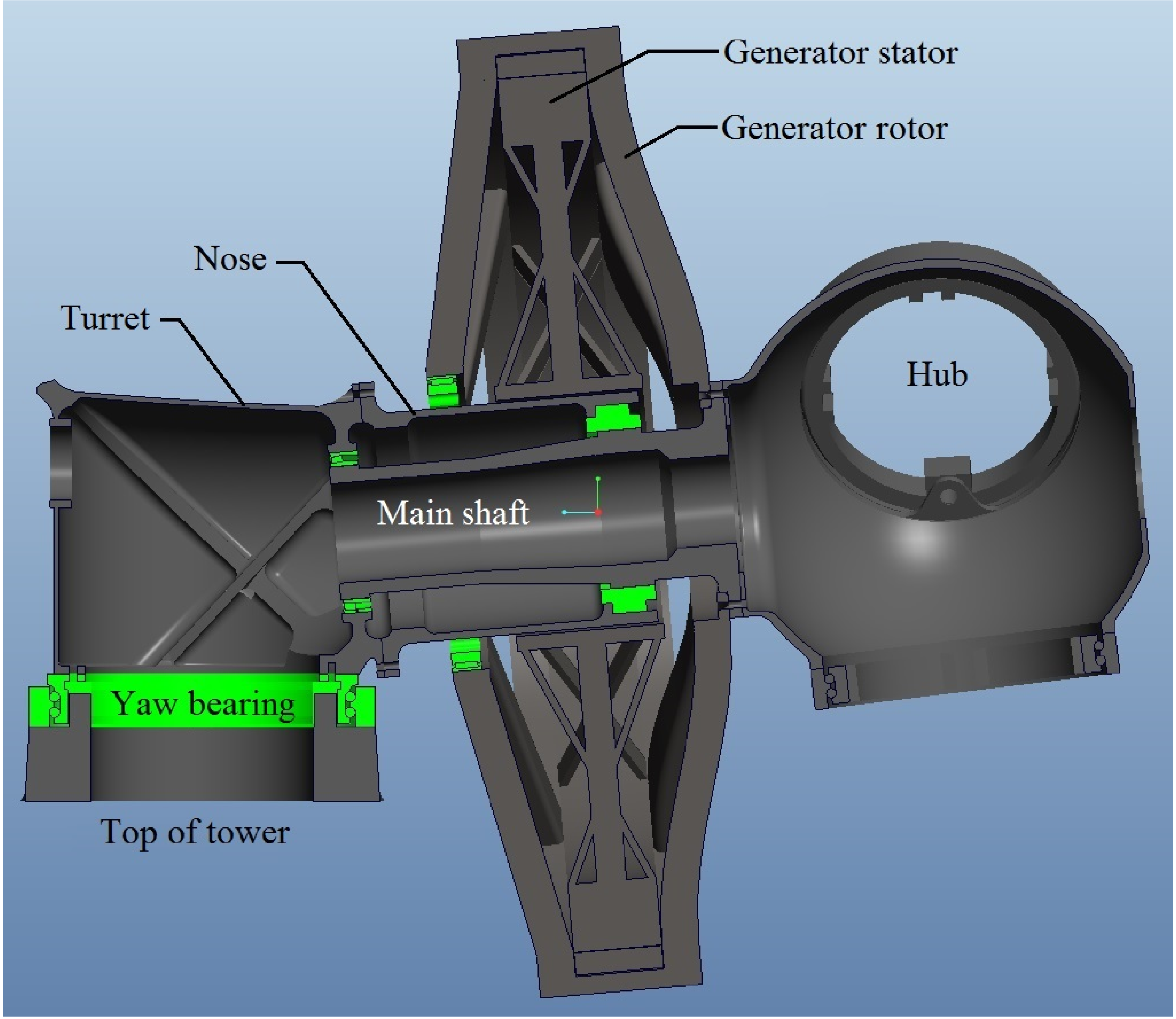
Transition piece +20 to +40 m
approx. 600 tonnes

30 m water depth

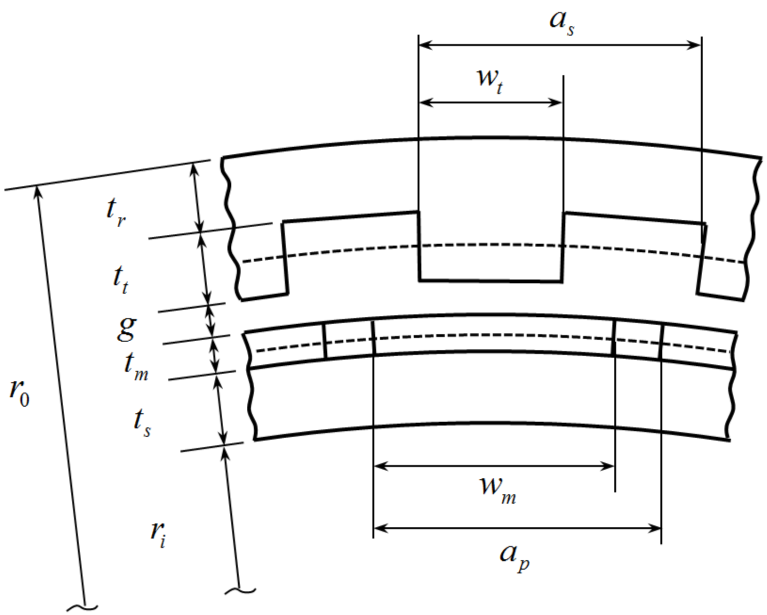
Monopile, -42 m to +20 m
9 m diameter
approx. 1500 tonnes

Dogger Bank seabed profile

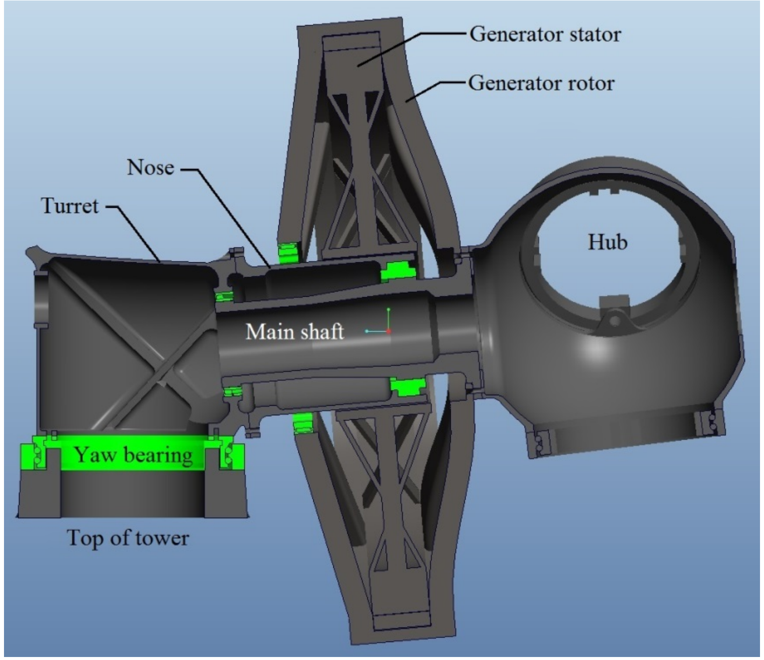
Direct-drive nacelle assembly



Generator



r_0	6030.2
r_i	5843.2
g	10.0
t_s	59.9
t_m	20.0
t_t	43.3
t_r	53.8
w_t	86.3
w_m	169.2
a_s	172.6
a_p	188.0

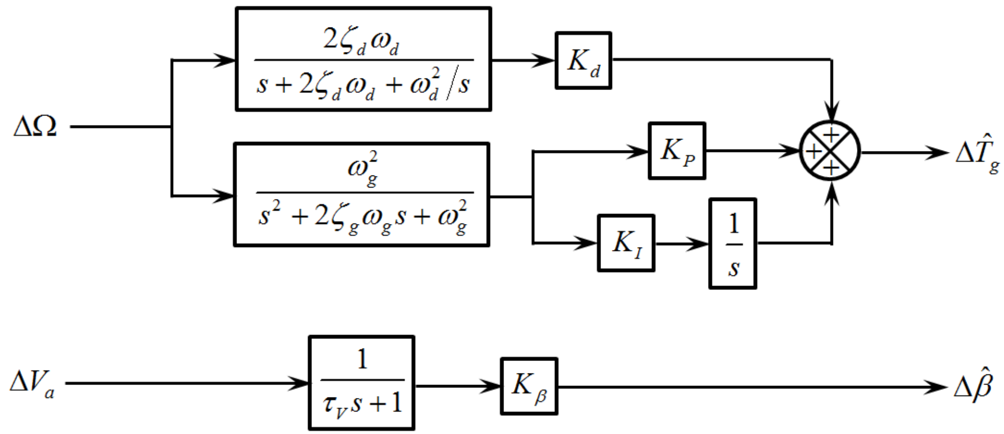


Generator

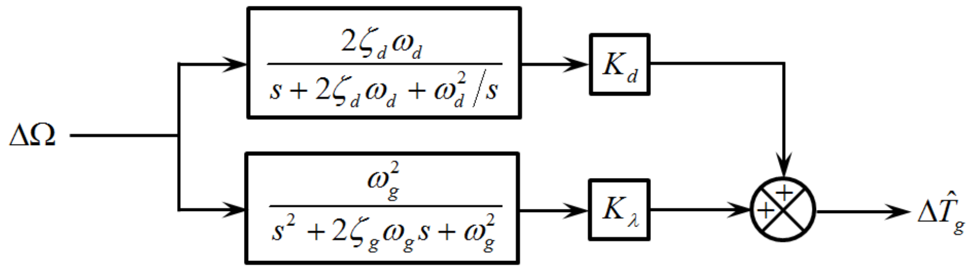
Parameter	Value	Units	Comments
P_r	10	MW	Rated power at generator terminals. Increased from 9.6 MW.
Ω_r	1.005	rad/s	Rated speed of the wind turbine and generator.
$\Omega_{cut\text{-}in}$	0.628	rad/s	Cut-in speed of the wind turbine and generator.
f_e	9.9-15.8	Hz	Electrical frequency range. Modified from 6.6-21.4 Hz.
V_r	3500	V	Nominal RMS line voltage. Increased from 3235 V.
i_a	1926	A	Nominal RMS phase current. Reduced from 2025 A.
	321	A	Nominal RMS winding current; 6 parallel current paths.
	3.97	A/mm^2	Nominal RMS copper current density.
b	1.770	m	Stack length. Increased from 1.218 m.
g	0.010	m	Air gap width.
n_p	198		Number of poles.
n_s	216		Number of slots.
N	23		Number of turns per winding.
	0.5		Copper fill factor = copper area/winding area of the cross-section.
R	0.0366	Ω	Phase resistance.[5] Increased from 0.0260 Ω.
L_a	5.29	mH	Phase inductance. Increased from 3.64 mH.
B_m	1.2	T	Residual magnetic field strength in magnets.
λ_k	4.47	Wb	Amplitude of winding flux due to magnets. Increased from 3.08 Wb.
	0.18		Fraction of rated resistive losses assumed for no-load losses.[6]
m_g	240	tonnes	Estimated total generator mass.[7] Increased from 200 tonnes.
η	0.954		Efficiency at rated power and speed.

Control: DTU Basic Wind Energy Controller

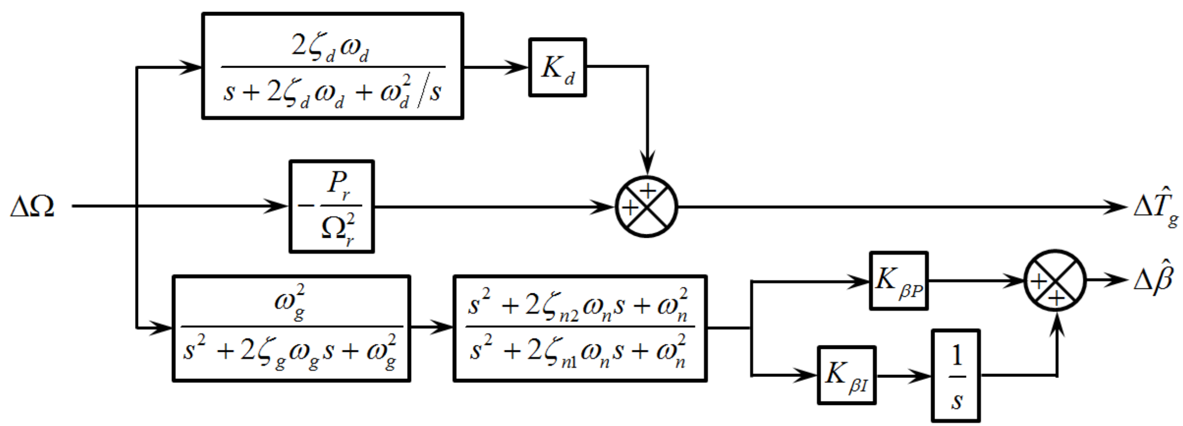
$V_\infty \leq 7$ m/s

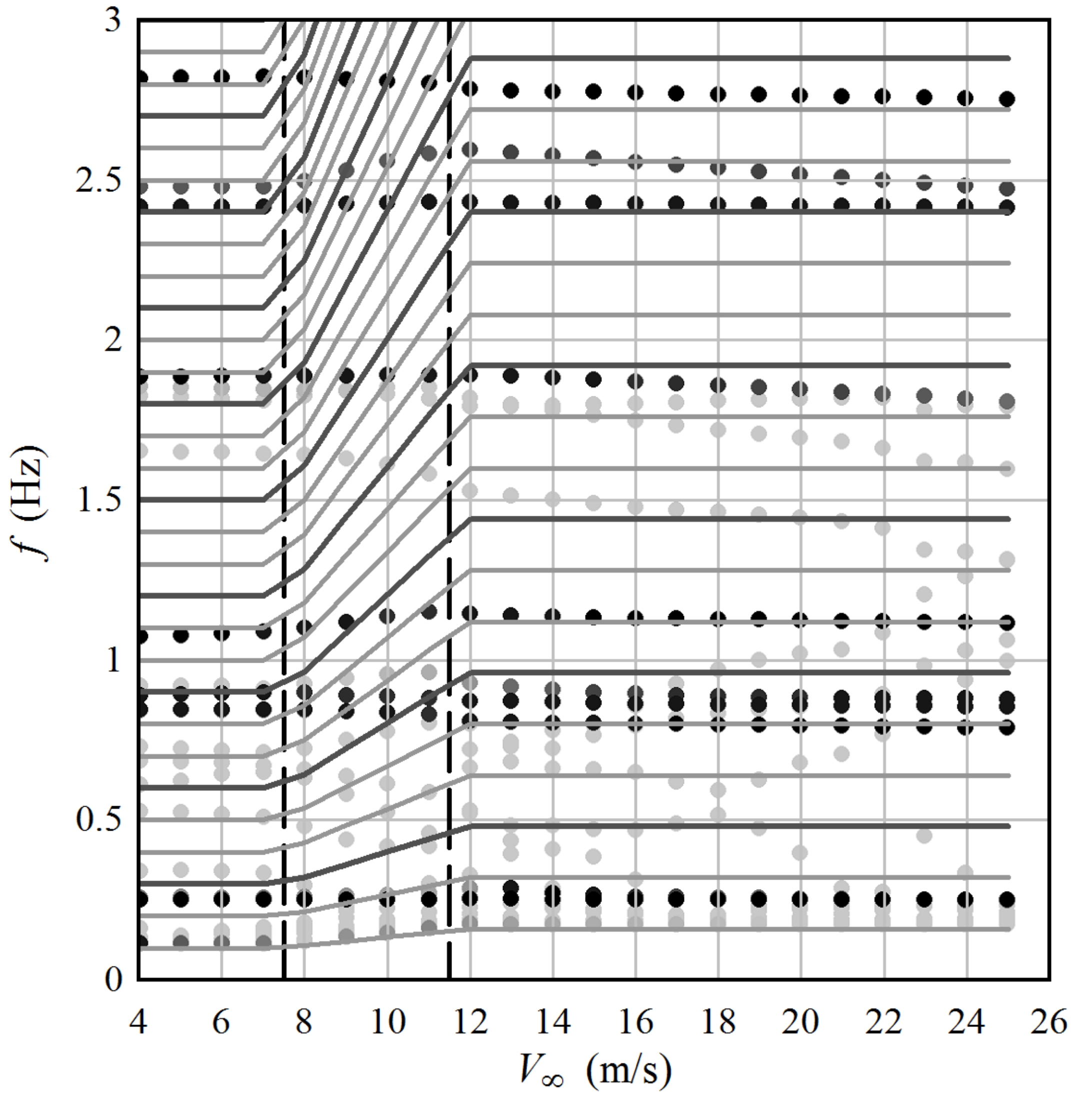


Variable-speed regime



Above-rated




3
2.5
2
1.5
1
0.5
0
f (Hz)
4
6
8
10
12
14
16
18
20
22
24
26
V_∞ (m/s)

Dogger Bank – Creyke Beck A

Base case for further trade studies

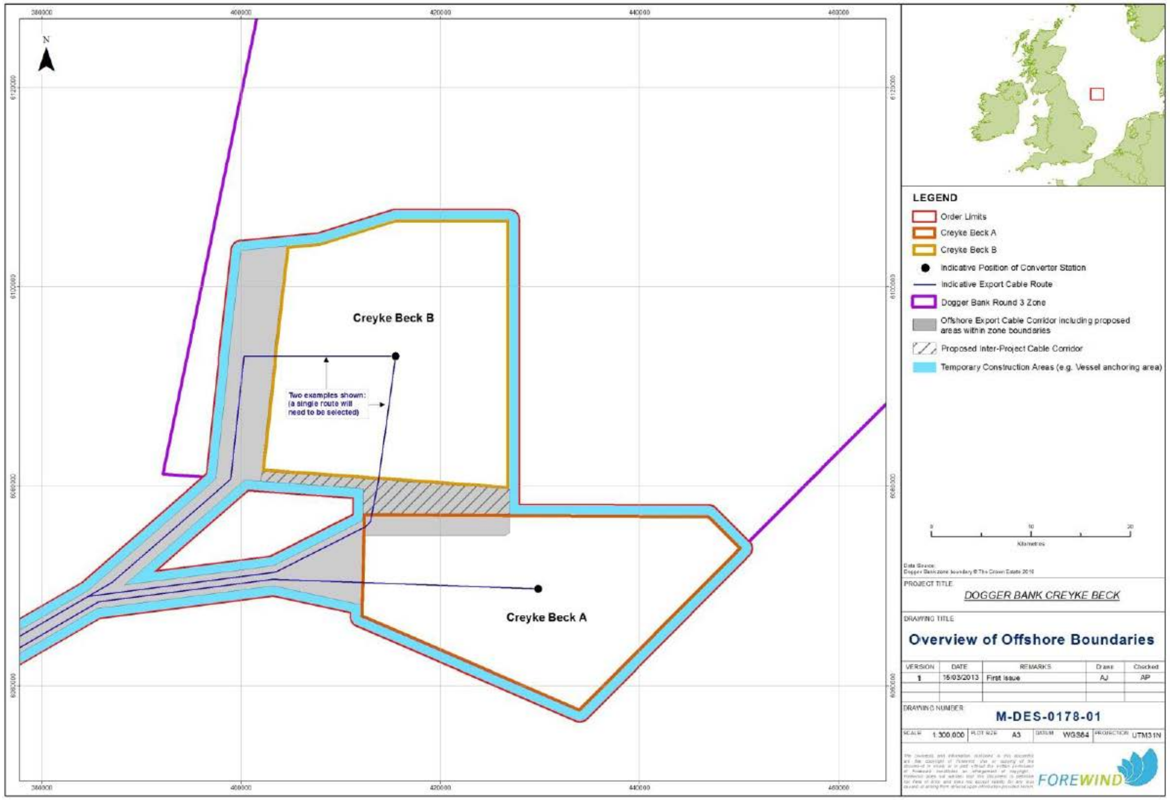
1.2 GW, 120 10 MW turbines, DTU rotor, 178.3 m diameter

Electrical designs:

Baseline: 33 kV collection grid, three MV/HV substations, HVDC to shore

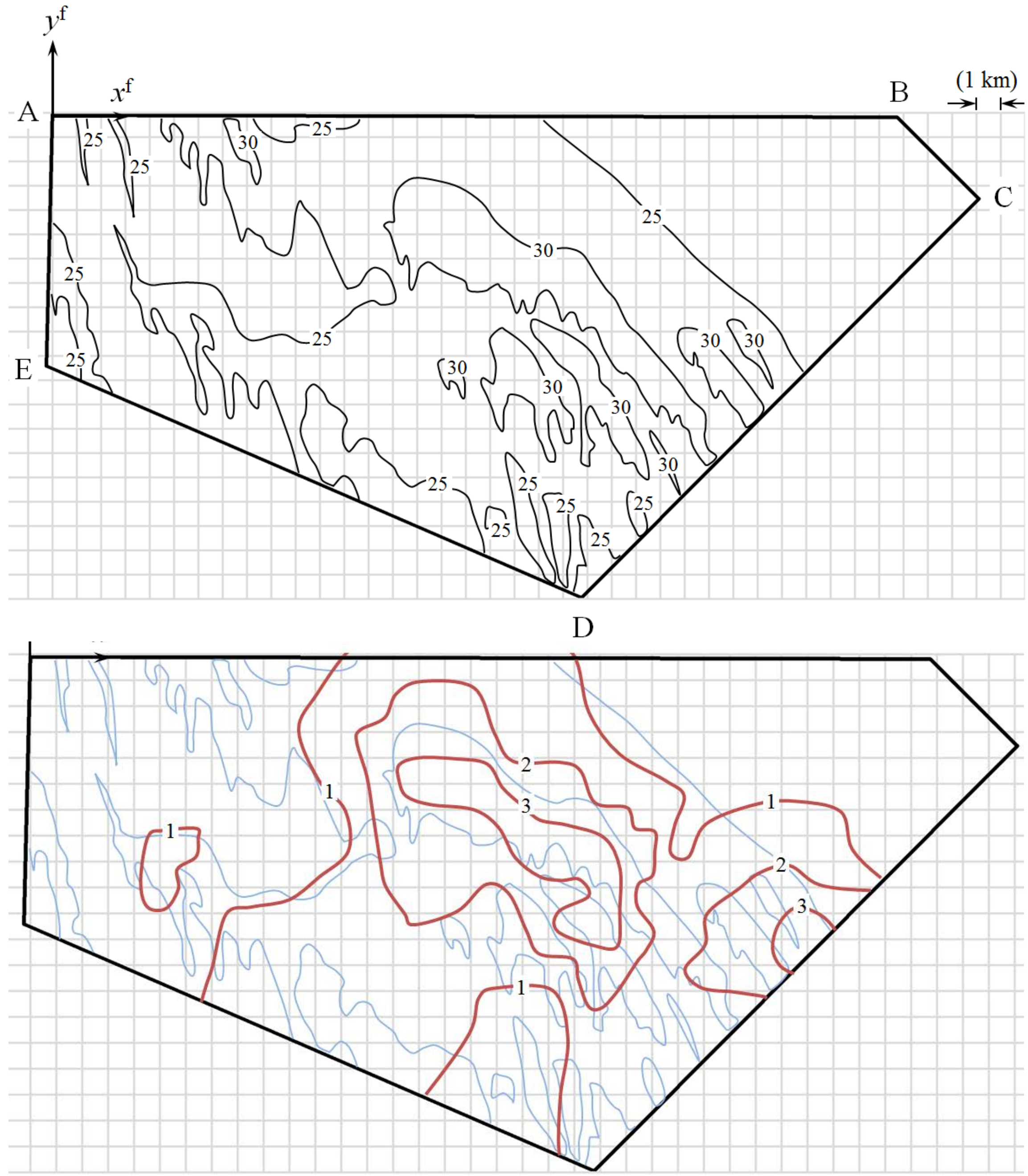
Upcoming technology: 66 kV collection grid, eliminate substations, HVDC to shore

Alternative: 66kV/220kV HVAC transmission

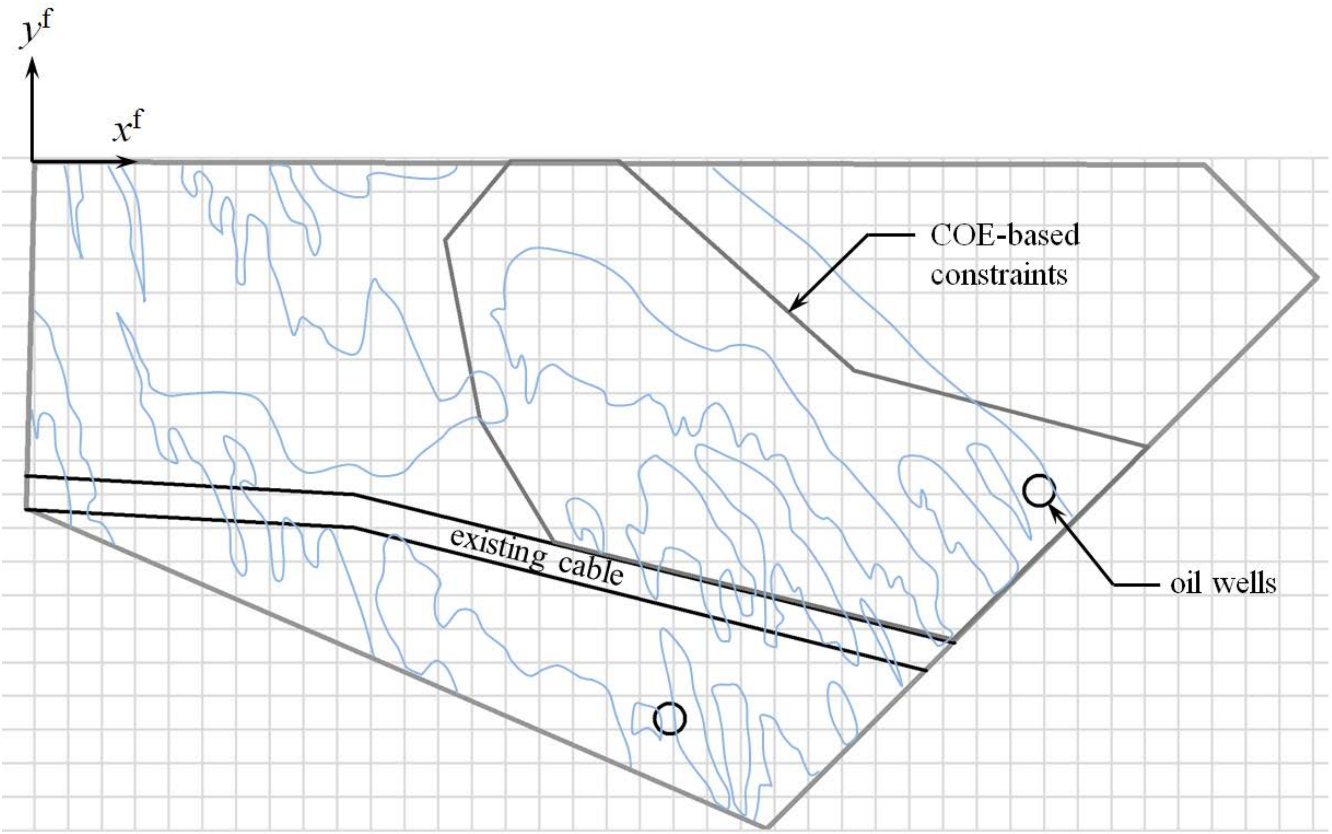


Forewind Consortium; *Dogger Bank Creyke Beck Environmental Statement: Chapter 5, Project Description*. 2013.

Creyke Beck A depth and cost trends



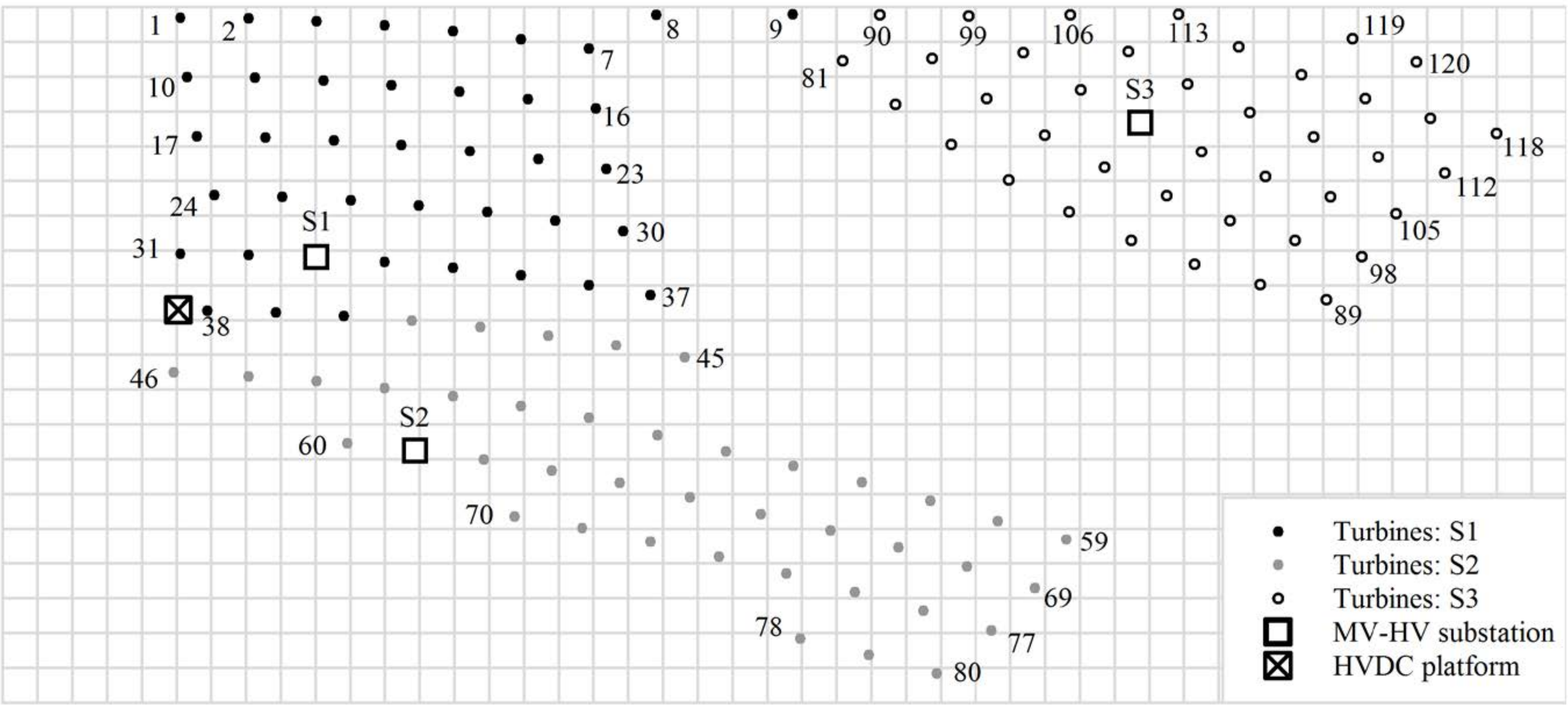
Creyke Beck A constraints



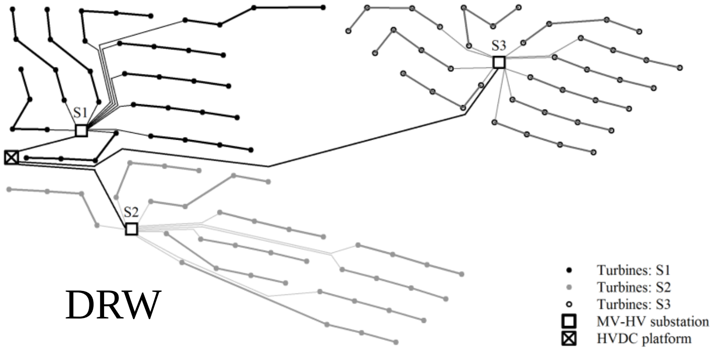
Roughly 10*D* spacing

Curved rows/columns to reduce sensitivity to wind direction

Electrical: Three blocks of 40 turbines, substations "in-pattern" for ease of navigation

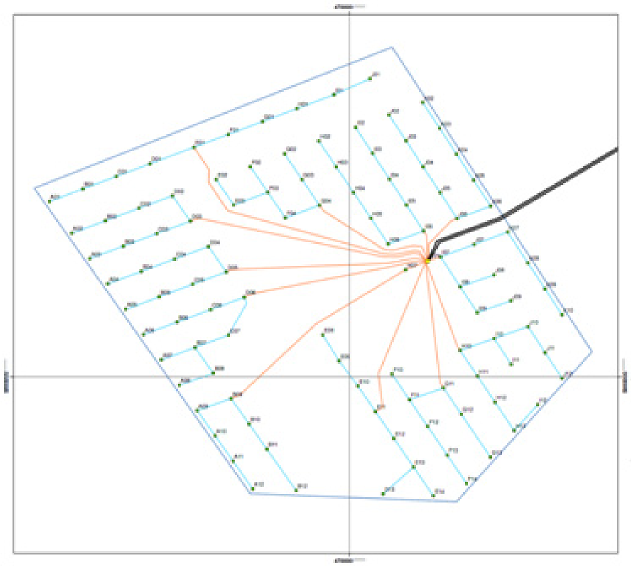


A comparison of layouts

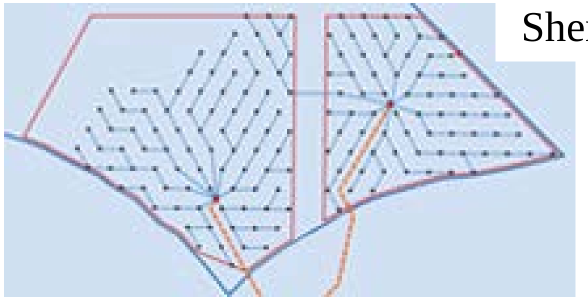


DRW

Sheringham Shoal



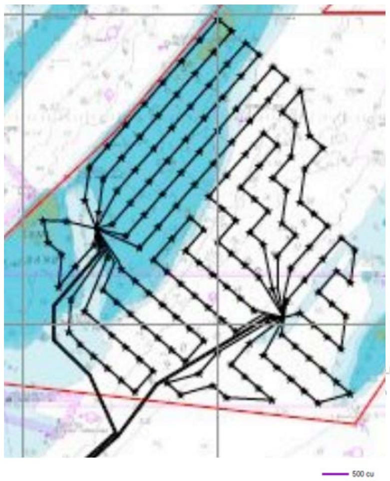
West of Duddon Sands



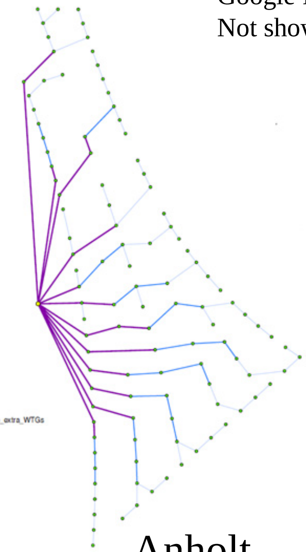
Gwynt y Môr

Sources: various public Internet locations, found by Google Pictures. Not shown to scale.

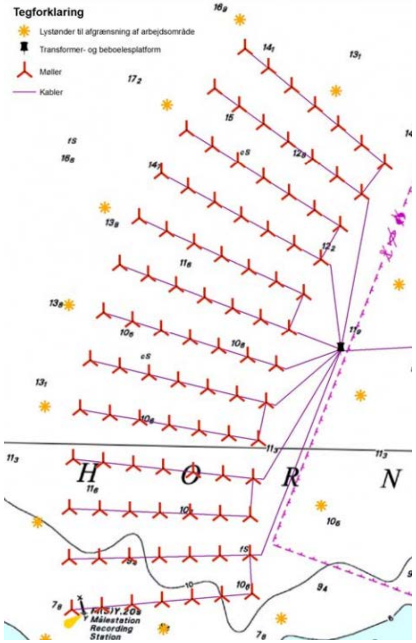
Greater Gabbard



London Array

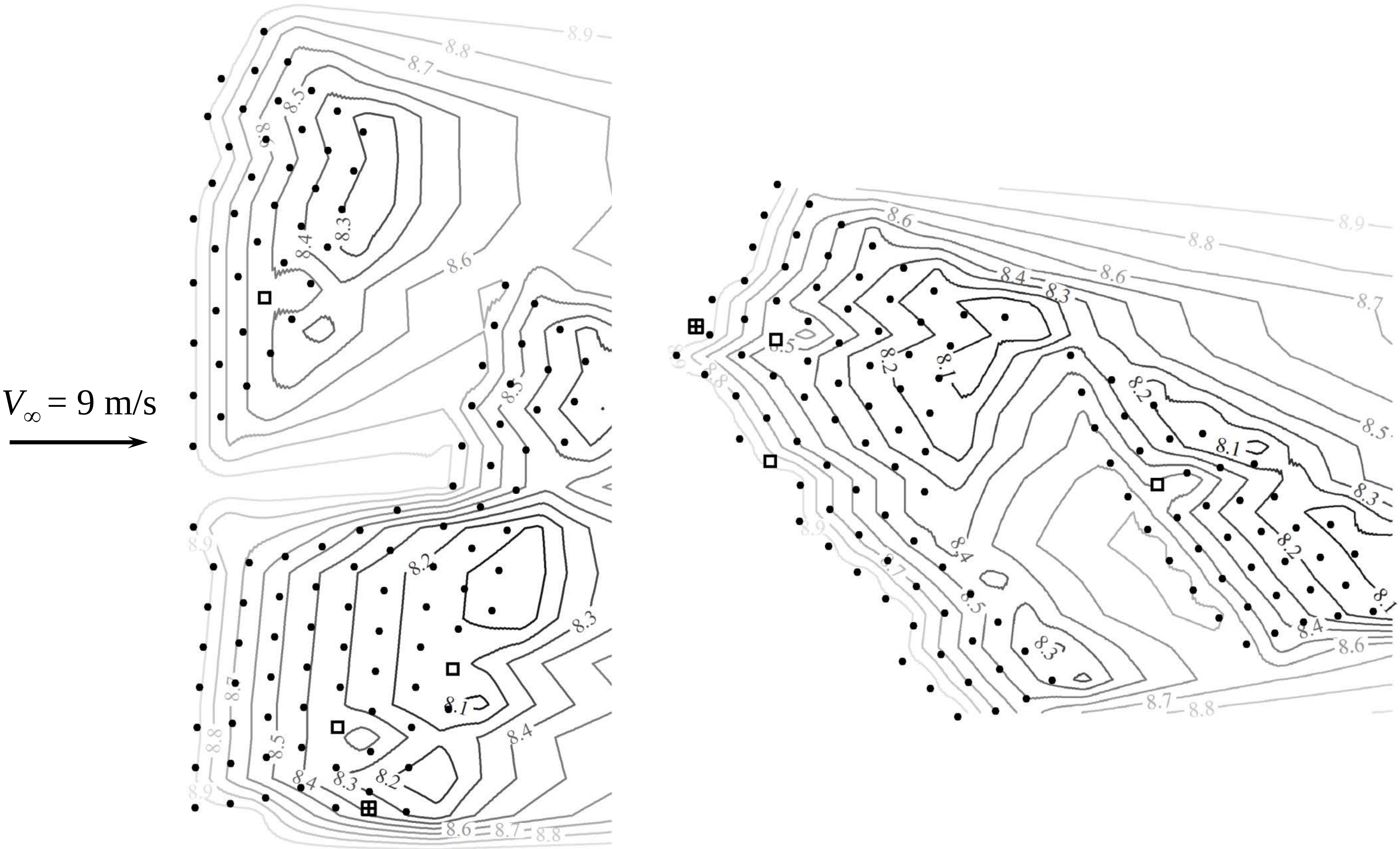


Anholt

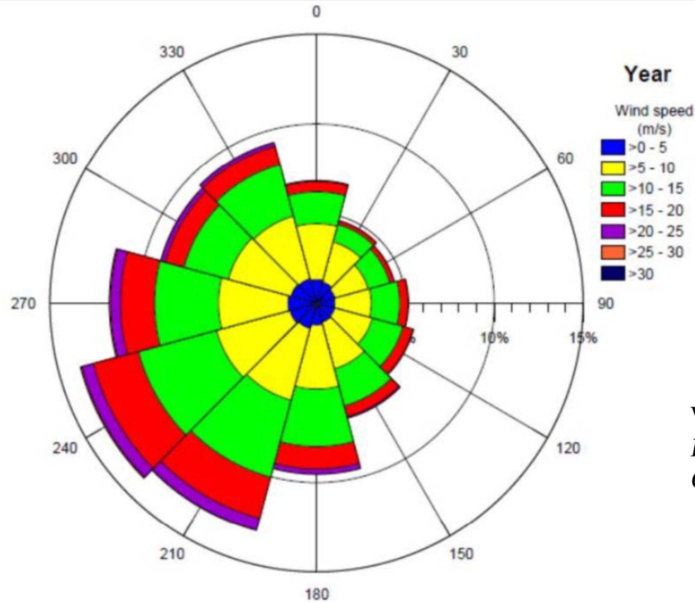


Horns Rev 2

Hub-height windspeeds computed with Viper 2D boundary-layer analysis



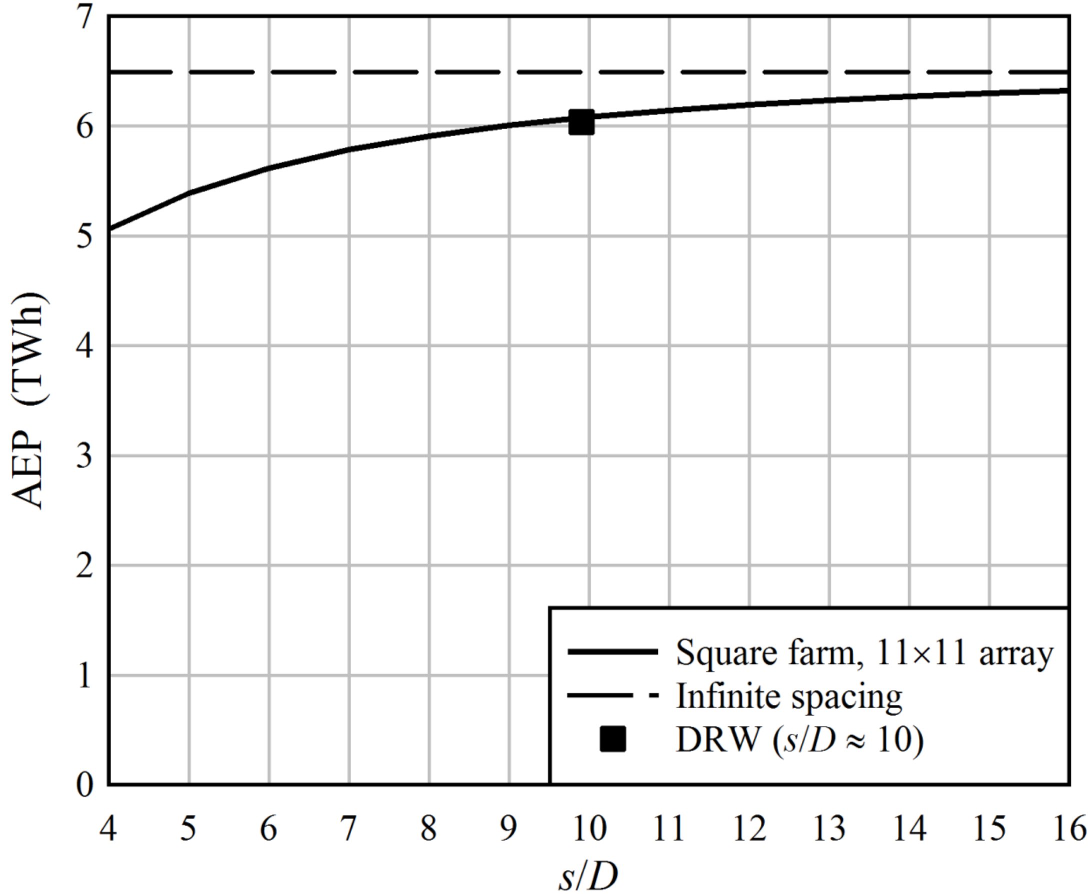
AEP computed by Viper



Wind rose: Forewind Consortium; *Dogger Bank Creyke Beck Environmental Statement: Chapter 5, Project Description*. 2013.

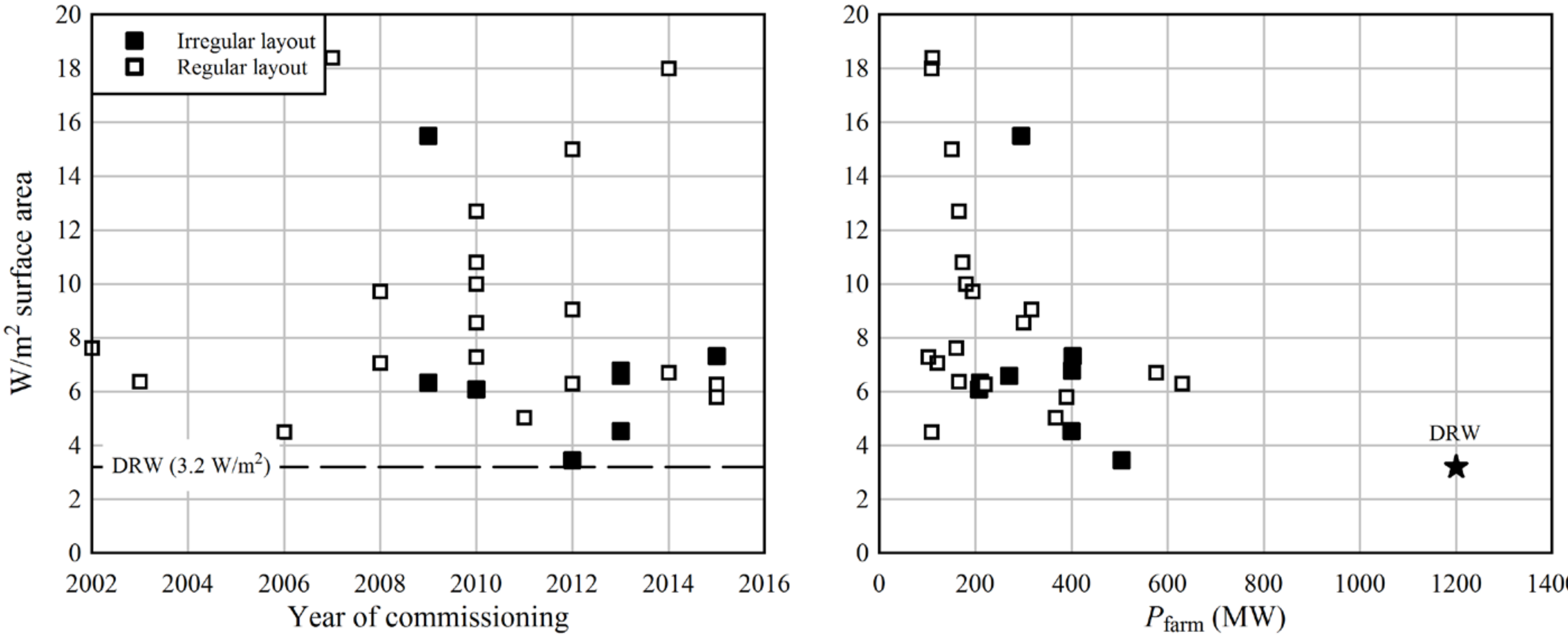
Contours show GWh/year

AEP versus spacing



Hypothesis: For wind farms with relatively uniform spacing, AEP depends primarily upon the spacing and not the shape of the outer boundary.

Have we chosen a good turbine spacing?



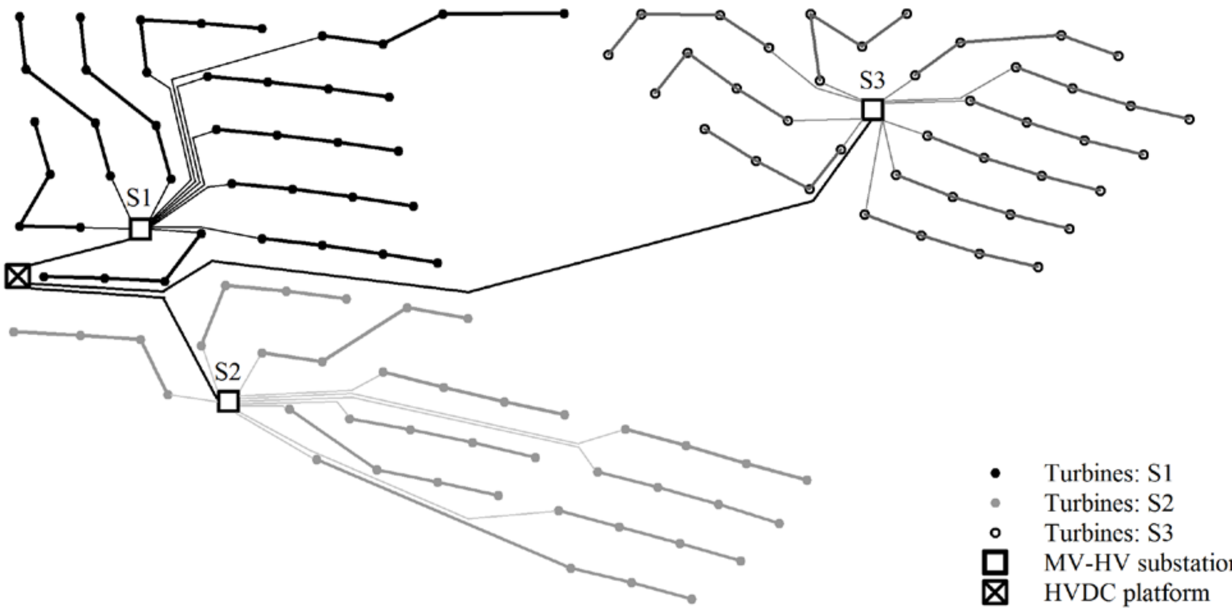
Hypothesis: Global (atmospheric boundary-layer) wake effects drive up the characteristic *s*/*D* spacing between turbines in very large wind farms, if area is not the primary constraint.

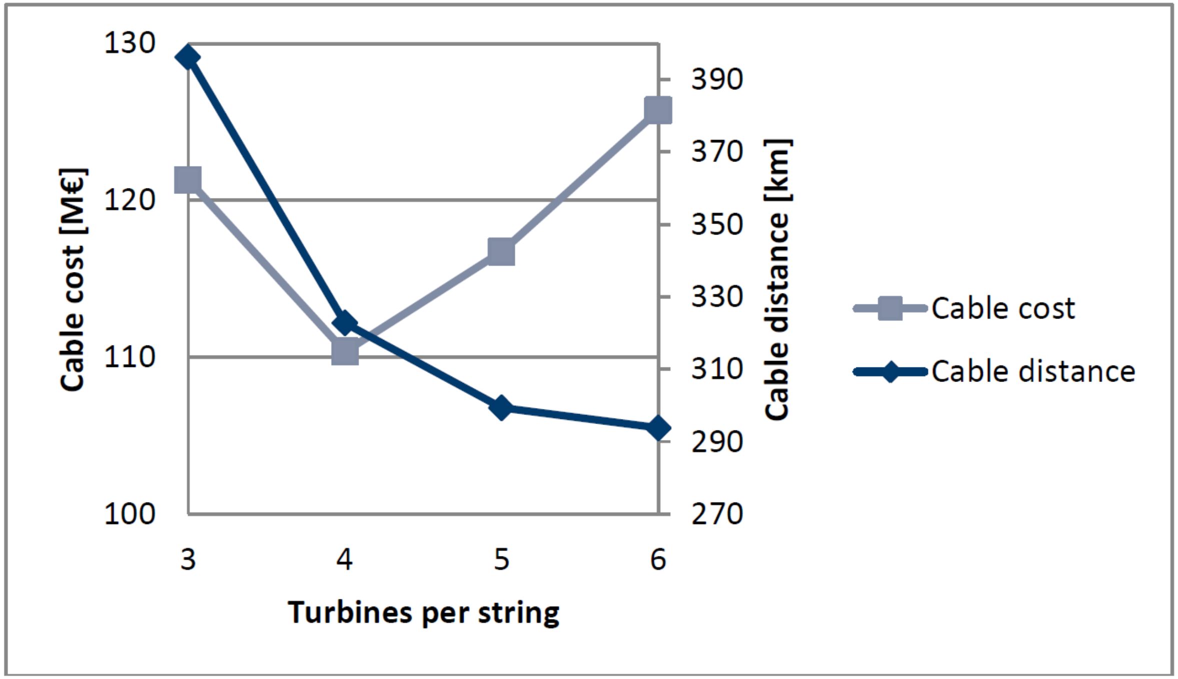
Hypothesis: Diminishing per-turbine costs of marine operations make higher turbine densities economical in "small" wind farms.

What effect does the areal cost of the offshore sector have on the optimal turbine density? Are coastal waters worth more than those far offshore like Dogger Bank?

It is relatively easy to rescale the existing pattern (depart from the "actual" Creyke Beck case).

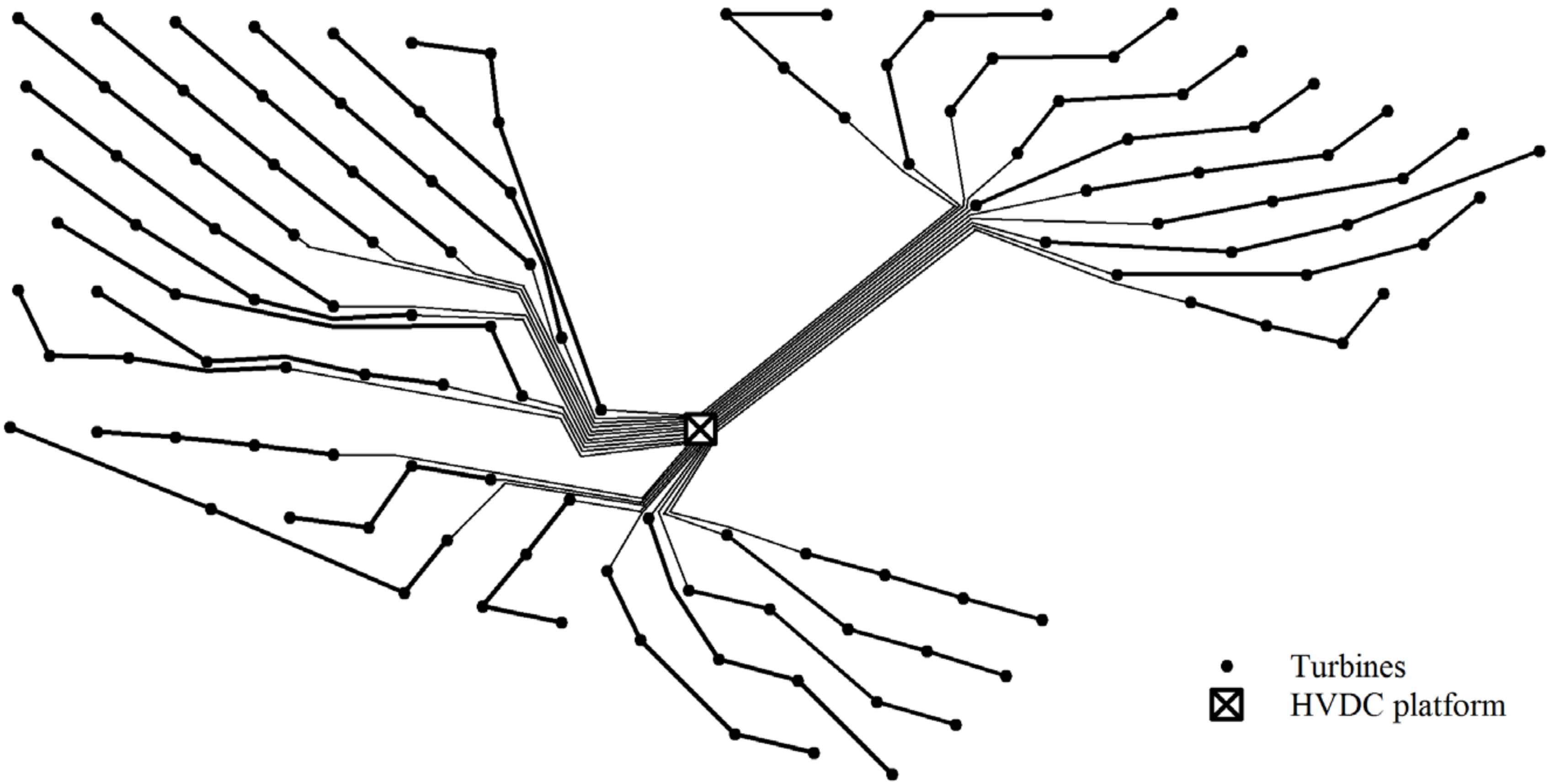
Turbines per string selected by a parametric study





Kirkeby H; NOWITECH Reference Wind Farm Electrical Design; Memo AN 14.12.15, Sintef Energy Research, 2014

66kV AC to HVDC, eliminate substations



Kirkeby H; NOWITECH Reference Wind Farm Electrical Design; Memo AN 14.12.15, Sintef Energy Research, 2014

Electrical: Voltage and substations

Internal grid lifecycle costs					
		33 kV		66 kV	
Infrastructure		Specification	Price [M€]	Specification	Price [M€]
WTG	Switchgear	120x	7,87	120x	10,88
Cables	Cables LV	396 km 33kV	130,37	328 km 66kV	91,55
	Cables HV	128,67 km 132 kV	128,70	128,67 km 132 kV	128,70
	Deployment	MV & HV	19,20	MV & HV	17,90
Substation	Platform	3x 66/132 kV	92,40	3x 66/132 kV	92,40
	Installation	18 days, 2 vessels	12,00	18 days, 2 vessels	12,00
Converter station	Switchgear	3x 132kV	2,76	3x 132kV	2,76
Energy losses	Losses	1 - 98.42 %	138,00	1 - 98.68 %	115,29
Total			531,30		471,48

Internal grid lifecycle costs					
		With substation		Without substation	
Infrastructure		Specification	Price [M€]	Specification	Price [M€]
WTG	Switchgear	120x	10,88	120x 66kV	10,88
Cables	Cables LV	328 km 66kV	91,55	490 km 66kV	154,22
	Cables HV	128,67 km 132 kV	128,70		
	Deployment	MV & HV	17,90	MV	16,65
Substation	Platform	3x 66/132 kV	92,40		
	Installation	18 days, 2 vessels	12,00		
Converter station	LV switchgear	3x 132kV	2,76	24x 66kV	2,18
Energy losses	Losses	1 - 98.68 %	115,29	1 - 99.34 %	57,65
Total			471,48		241,58

Kirkeby H; NOWITECH Reference Wind Farm Electrical Design; Memo AN 14.12.15, Sintef Energy Research, 2014

Link to IEA Task 37 on Wind Energy Systems Engineering

Task 2.1: Reference wind turbines

Task 2.1.0: Specify a common data format for exchanging aeroelastic/control/electrical descriptions of onshore and offshore wind turbines, suitable for building models in typical wind turbine simulation programs.

Task 2.1.1: 3 MW Low-wind Onshore Reference Turbine Development

Task 2.1.1.1: Design specifications for a 3.x MW reference wind turbine with a geared drivetrain, targeting the onshore/Class III market segment.

Task 2.1.1.2 Upscale an existing 2.4 MW direct-drive wind turbine design to the 3.x MW range using established procedures.

Task 2.1.1.3 Design the reference 3.x MW Class III geared wind turbine.

Task 2.1.1.4 Design review and approval by OEM industry participants (Nordex, Vestas, Siemens, GE and DNV GL)

Task 2.1.2 10 MW offshore reference turbine with a direct-drive generator. (lead: SINTEF)

Task 2.1.2.1 ...

Task 2.2: Reference wind plants

Task 2.2.0 Catalogue offshore and onshore wind plants where we know we have data and identify what types of data are available for each

...

Task 2.2.4 Select and establish plant design criteria for a series of reference wind plants

Task 2.2.5 Develop reference wind plant 1 (low-wind onshore site)

Task 2.2.6 Develop reference wind plant 2 (high-wind offshore site)

Deliverables:

D2.1.1 Specifications document for the 3.x and 10 MW reference wind turbines

D2.1.2 Publication of the refined 3.x MW geared wind turbine design

D2.1.3 Publication of the refined 10 MW direct-drive wind turbine design

D2.2.1 Specifications document for the reference wind plants

D2.2.2 Publication of reference onshore plant 1

D2.2.3 Publication of reference offshore plant 2

Link to IEA Task 37 on Wind Energy Systems Engineering

Task 3.1: Benchmarking MDAO for wind turbines
- Task 3.1.1: Phase 1 benchmarks: Rotor only
  - 3.1.1a: Benchmarking of rotor aero only
  - 3.1.1b: Benchmarking of rotor aero and structure
- Task 3.1.2: Phase 2 benchmarks: full turbine
  - 3.1.2a Benchmarking of full turbine TBD

Task 3.2: Benchmarking MDAO for wind plants
- Task 3.2.1 Layout optimization onshore
- Task 3.2.2 Layout optimization offshore

(Tentative) Controls optimization

(Tentative) Electrical analysis and optimization

(Tentative) LCOE analysis and optimization (O&M)

Deliverables

D3.0.1: Online portal / information clearinghouse for MDAO research and software

D3.0.2: Report on benchmarking scope, process and evaluation criteria

D3.1.1: First turbine benchmark finalized and reported

D3.1.2: First plant benchmark finalized and reported

D3.2.1: Second turbine benchmark finalized and reported

D3.2.2: Second plant benchmark finalized and reported