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Wake measurements for code validations

Deliverable D11: EU - TOPFARM

Hansen, Kurt Schaldemose

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Technical Report

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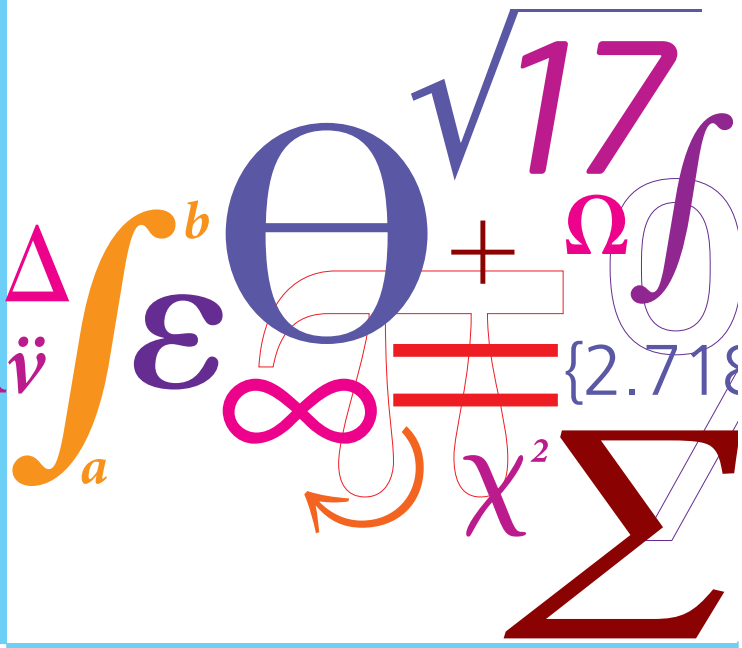

Kurt S. Hansen
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DTU Mechanical Engineering
Department of Mechanical Engineering

Contact information
Kurt Schaldemose Hansen,
Senior Scientist
DTU Mechanical Engineering
Technical University of Denmark
DK-2800 Lyngby
Denmark
Phone +45 45254318
Email ksh@mek.dtu.dk

Printed at
DTU Mechanical Engineering
Section of Fluid Mechanics
Technical University of
Nils Koppels Allé, Bld. 403
DK- 2800 Kgs. Lyngby
Denmark
Phone (+45) 45 25 43 00
Fax (+45) 45 88 43 25

www.mek.dtu.dk

Wake measurements for code validations
Deliverable D11: EU - TOPFARM

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By
Kurt S. Hansen,
Department of Mechanical Engineering
Technical University of Denmark, DTU

June 2009

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ABSTRACT
As part of the EU-TOPFARM project a large number of datasets have been identified for verification of wind farm climate models, aeroelastic load and production models of turbines subjected to three dimensional dynamic wake wind field and the aeroelastic production modeling of a whole wind farm developed in the project.
This report identifies a number of measurement datasets; which is available for model validations in the EU-TOPFARM project. The datasets is presented with a very short summary of the test setup and a principle site layout illustration.

Summary of EU-TOPFARM program

NEXT GENERATION DESIGN TOOL FOR OPTIMISATION OF WIND FARM TOPOLOGY AND OPERATION

Strategic objectives:
Electricity from wind/ Innovative wind farms, turbines and components for reliable electricity generation at reduced costs

TOPFARM abstract:
During recent years, wind energy has moved from an emerging technology to become a nearly competitive technology. This fact, coupled with an increasing global focus on environmental concern, as e.g. expressed in the Kyoto protocol, and a political desire on a certain level of diversification in the energy supply, ensures wind energy an important role in the future electric energy supply market. An increasing part of the turbines to be installed in the future are foreseen to be sited in large wind farms.
Establishment of large wind farms requires enormous investments putting steadily greater emphasis on *optimal topology design and control* of these. Today, the design of a wind farm is based on an optimisation of the power output only, whereas the load aspect is treated only in a rudimentary manner, in the sense that the wind turbines are required only to comply with the design codes. However, a *complete* optimisation of design and control of these farms requires, in addition to the power production, a *detailed* knowledge of the loading of the individual turbines. This is not a trivial problem.
The *power production* and *loading*, related to turbines placed in a wind farm, deviate significantly from the production- and loading pattern of a similar stand-alone wind turbine subjected to the same (external) wind climate. Crucial factors in this connection are the relative position of the individual wind turbines and the wind turbine control/operation strategy for wind turbines interacting through wakes.
To achieve the *optimal economic output* from a wind farm, an optimal balance between capital costs, operation and maintenance costs, fatigue lifetime consumption and power production output is to be determined on a rational background. The overall objective of this project is to establish this background in terms of advanced dynamic wake load models, power production models, cost models, control strategy models and area constraints, and subsequently to link these models in an optimization algorithm. The design variables for the optimisation model are the relative position of the wind turbines (including the possibility for positioning a given number of turbines in one or more wind farms) and wind turbine control strategies on wind farm level as well as for the individual wind turbine.

Contents

1 Introduction

TOPFARM Work packages 1-3 encompass a range of advanced sub-models. The objective of WP4 is to verify these, as well as their mutual interaction, in full-scale environments. Model predictions are to be compared with available power production- and structural measurements as well as detailed flow measurements.

To meet the objectives of WP4, discussions on the data requirements have been initiated, and relevant measurements have been identified. To this end, MEK.DTU has identified a list of potential data sources, categorized in 3 groups according to the type of application, which have to be validated.

The 3 characteristic groups of data are identified as:

1) Wind turbine – mast interaction; the mast is located on a fixed position, which results in a limited sector with applicable measurements. This group of data is represented with 9 different sites ranging from small to large wind turbines located in Denmark, Sweden and the Netherlands. Some of the measurements are available as time series from [16] and are mainly useful when investigating the wake properties, while the remaining part of measurements are only available in a compiled version e.g. as mean value plots.

2) Wind turbine – wind turbine interaction; the response of the downwind turbine(s) is used for measuring/identifying the wake properties. This case is mainly useful for analysis of (average) directional wake behavior inside large wind farms. The data category is presently represented by 8 different wind farms ranging from small to large wind farms placed in Denmark, the Netherland and in UK.

3) Wind turbine – direct wake measurement; the wake is measured directly with a measuring device (LiDAR) mounted on the wake generating wind turbine and offers the possibility for analysis of instantaneous wake properties. This data category is presently represented with a dataset from a 95 kW experimental wind turbine placed in Denmark and a dataset from a full scale experiment on a 80m/2.5MW wind turbine located in Tjæreborg, DK.

Structural wind turbine loads measured on wind turbines inside wind farms are only available from a limited number of projects.

The main part of datasets is restricted both in distribution and in use, due to individual confidentiality agreements, but is stored on internal servers at MEK.DTU. The datasets are available for code validations within the TOPFARM environment in a compiled form (e.g. as processed diagrams, figures and reports).

The remaining datasets are available through the "Database on Wind Characteristics" [16] without restrictions, as described in Annex A.

The wind turbine operational parameters used in the tables are defined as:

FS	Fixed Speed	VS	Variable Speed
SC	(Passive) Stall Control	ASC	Active Stall Control
PC	Pitch Control		

2 Wind turbine – mast interaction

2.1 Nordtank - 3D measurements, Risø, DK

Site	Risø Campus, Roskilde
Wind turbine	Nordtank 550 kW (FS,SC)
Wind turbine diameter	41 m
Mast	36 m
Spacing	Appr. 1½D (=55m)
Instrumentation	3 x Sonic, h=36 m located on a boom perpendicular to the flow direction, Figure 1.
Periods	Campaign, appr. 450 hours
Measurements	10 min mean and st.dev.
Comments	Wake measurements are only available for an eastern wind sector (103º±30). The 3D sonic statistics can be merged with wind turbine measurements from the Nordtank database.
Purpose	Dataset recorded is as part of EU-ACCUWIND
Contact persons	Kurt S. Hansen; MEK.DTU & Troels.F. Pedersen; RISØ.DTU
Data storage	Internal Risø dataserver at RISØ.DTU.
Data owner	RISØ.DTU
Data accessibility	Restricted to EU-ACCUWIND and RISØ DTU

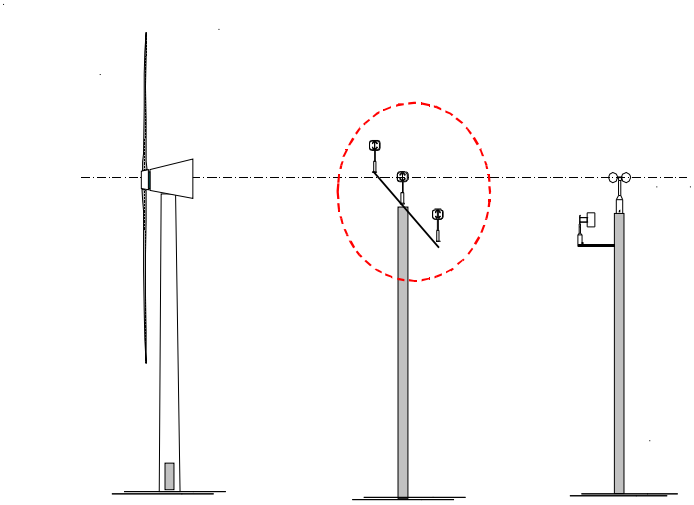

Figure 1: Measurement setup for near wake 3D measurements on the 500kW Nordtank wind turbine (DK).

2.2 Nordtank – time series, Risø, DK

Site	Risø Campus, Roskilde
Wind turbine	Nordtank 550 kW (FS,SC)
Wind turbine diameter	41 m
Mast	36 m
Spacing	Appr. 2½D (=100m)
Instrumentation	Top mounted cup h=36 m, Figure 2.
Periods	>1000 hours
Measurements	1) Basic statistics (10 min. mean and st.dev.) 2) time series, sample with 35 & 1 Hz
Comments	Wake measurements are only available in eastern wind sector=103º±30. Statistics are available from the Nordtank database.
Purpose	Education
Contact persons	Kurt S. Hansen; MEK.DTU & Uwe.S.Paulsen; RISØ.DTU
Data storage	www.winddata.com/nordtank
Data owner	DTU
Data accessibility	No restrictions

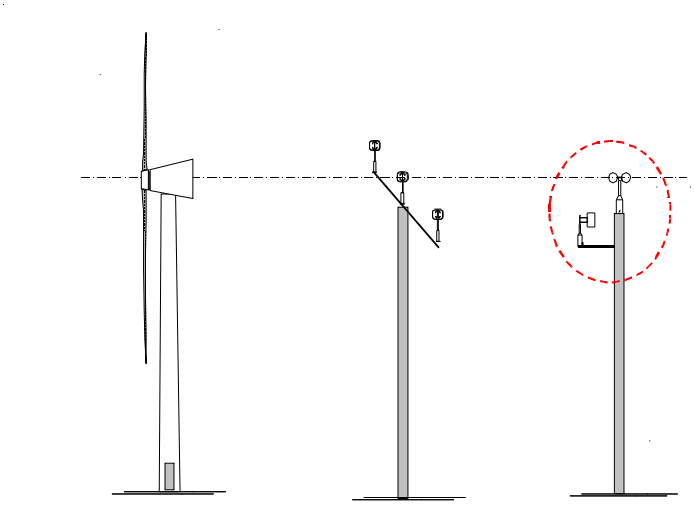

Figure 2: Measurement setup for 1D wake measurements on the 500kW Nordtank wind turbine (DK).

2.3 Nibe Wind turbines, Nibe, DK

Site	Nibe Bredning, Jutland
Wind turbine	Nibe 2 x 630 kW, h=45m; (FS,PC)+(FS,SC) demonstration wind turbines (erected in 1979 & 1980)
Wind turbine diameter	40 m
Mast (s)	56, 64, 64 & 64 m
Spacing	2.5D North, 1D North, 1D South, 2.5D South Double wake situations are included
Instrumentation	M1:Cups, h=3,10, 25, 45 & 56 m M2,3,4:Cups, h=15, 25, 31, 38, 56 & 64 m
Periods	Jan 1985 – Jul 1987
Measurements	1 min mean and st.dev.; > 24.000 records
Comments	Wake measurements are only available in southern or northern wind sectors.
Purpose	Demonstration project & EU-Project: Wake measurements on the Nibe wind turbines in Denmark [1].
Contact person	Kurt S. Hansen; MEK.DTU
Data storage	Raw data is not available, but setup details and results are documented in [1]. The wind speed deficits have been digititized - based on plots.
Data owner	RISØ DTU & National Power UK
Data accessibility	No restictions

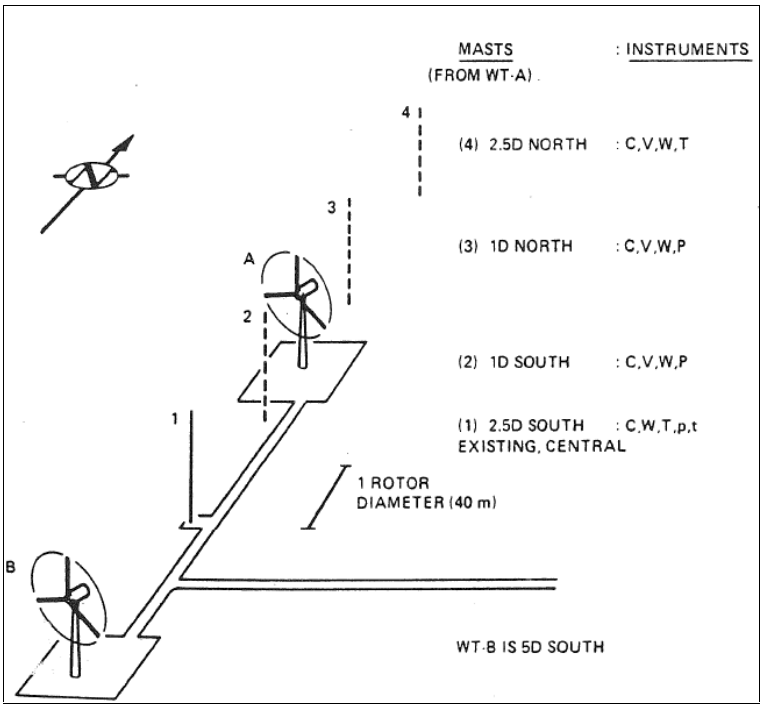

Figure 3 Schematic view of the Nibe wake measurement setup, from [1]

2.4 Tjæreborg, Esbjerg, DK

Site	Tjæreborg Enge, Esbjerg
Wind turbine	2MW/60m ELSAM demonstration wind turbine, (FS,PC). WT has been removed.
Wind turbine diameter	60 m
Masts	2 x 90 m,
Spacing	2 x D, direction=67 & 242º
Instrumentation	Cup and vanes, h=10, 30, 45, 60, 75 & 90 m on 2 masts.
Period	1988-1993
Measurements	1)10 min statistics (mean, std, min, max) – 5YR 2) 64 Hours of time series wit a sampling rate of 25 Hz.
Comments	1) Time series (T=600-3600sec) 2) Large number of capture matrix time series (structural loads) with a duration of 180 sec.
Purpose	2MW/60m wind turbine demonstration project
Contact person	Kurt S. Hansen/MEK.DTU
Data storage	Http://www.winddata.com/ ; site=tjare
Data owner	ELSAM (DONG Energy & Vattenfall AB)
Data accessibility	No restrictions

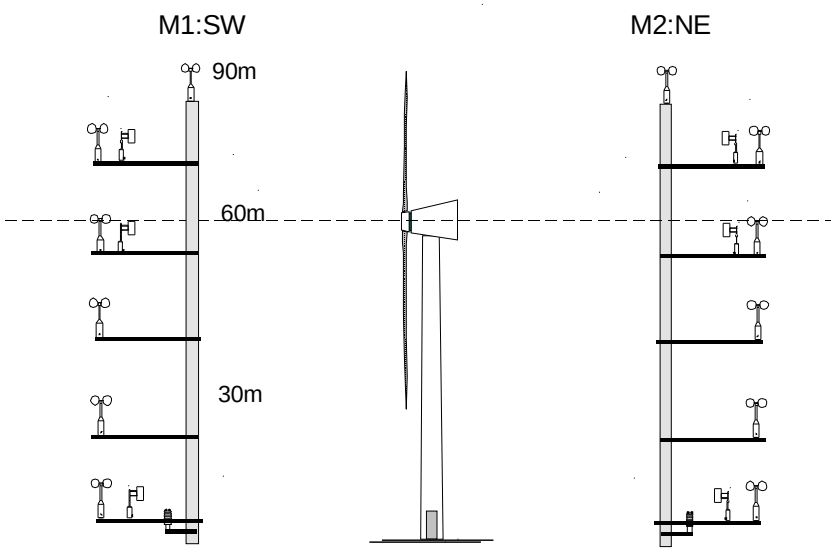

Figure 4: Site layout for the Tjæreborg experiment in 1988-1992.

2.5 Alsvik, Gotland, SE

Site	Alsvik onshore wind farm, Gotland, Sweden
Wind turbine	Danwin 4 x 180 kW, hub=30m, (FS,SC).
Wind turbine diameter	23 m
Masts	2 x 54 m
Spacing	1 – 7 x D
Instrumentation	Cup & vanes; h=10,18,24,31,36,41,47,53 m
Periods	June/1991 – August/1994
Measurements	1) Appr. 17500 hours of time series with a sampling rate of 1.0 Hz. 2) Individual WT power as 60 min. statistics for wt #1, #2 & #3 (mean,std,min,max)
Comments	Time series of power and structural loads are available from TG/SE.
Purpose	Structural measurement program on 4 (small) wind turbines grouped in a wind farm [2].
Contact persons	Kurt S. Hansen/MEK.DTU & Hans Ganander/TG
Data storage	http://www.winddata.com/; site=alsvik
Data owner	Teknikgruppen (TG/SE)
Data accessibility	No restrictions

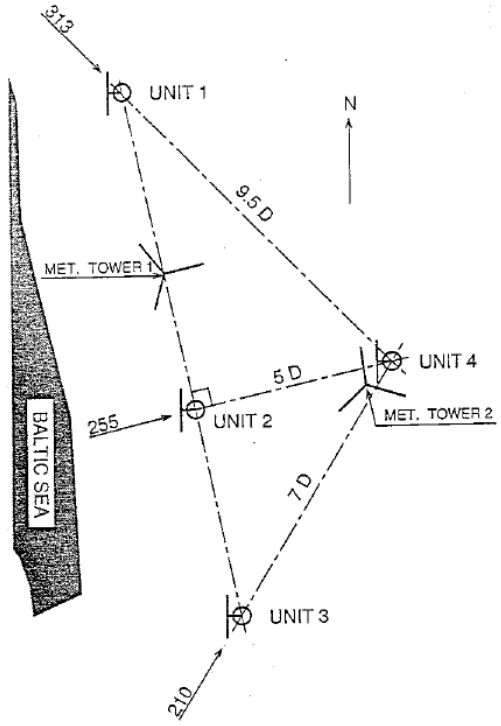

Figure 5: The Alsvik, SE site with 4 wind turbines (T1, T2, T3 & T4) and 2 masts (M1 & M2) from [2].

2.6 Sexbierum, NL

Site	Sexbierum onshore wind farm, The Netherlands (wind farm has been removed).
Wind turbine	18 x Holec 180 kW, hub=35m, (VS,SC)
Wind turbine diameter	30 m
Masts	M1..M7; h= 35 – 47 m
Instrumentation	1) Cup and vanes at hub height on 7 masts 2) 3 D propeller anemometers
Spacing	2.5, 5.5 & 8 x D
Measurements	Wake deficit plots based on 60 s mean values are reported in [3]
Period	June – November 1992.
Comments	Time series are not available.
Purpose	Wake and structural measurement on 18 wind turbines grouped in a wind farm.
Contact person	Kurt S. Hansen/MEK.DTU
Data storage	Deficit plots are available from report [3].
Data owner	TNO & KEMA,NL
Data accessibility	No restrictions

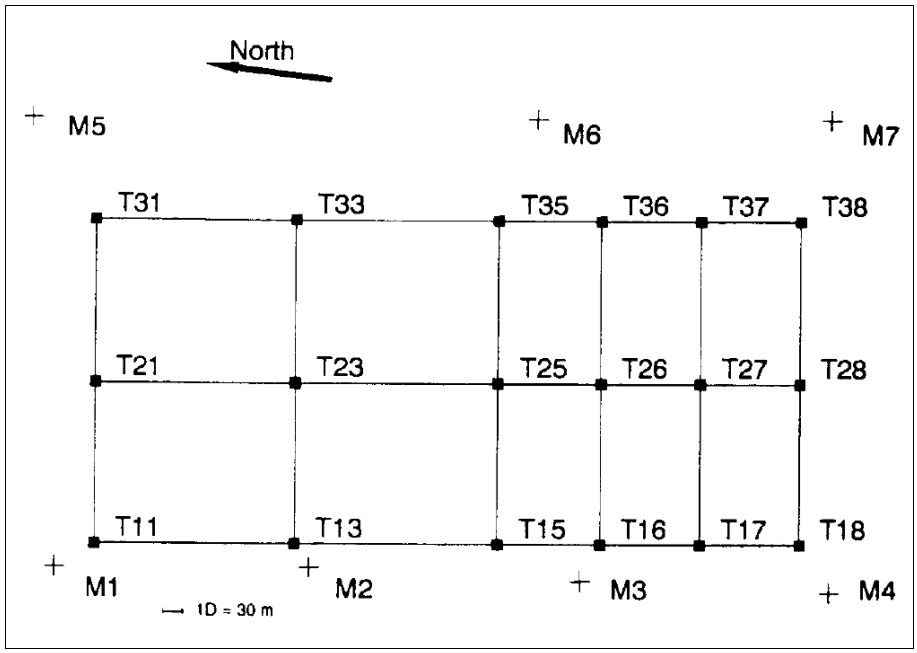

Figure 6: Site layout for Sexbierum wind farm, NL consisting of 18 wind turbines (T11..T38) and 7 masts (M1..M7) from [3].

2.7 Vindeby, Offshore, DK

Site	Vindeby offshore wind farm (DK)
Wind turbine(s)	11 x Bonus 450 kW, h=37 m (FS,SC).
Wind turbine diameter	35 m
Masts	M1: onshore mast, h=48.7 m M2&M3: offshore masts, h= 48 m
Spacing (wt => mast)	8.5D & 9.4D
Instrumentation	M1:Cup and vanes, h=7,10,20, 34,37&48 m M2:Cup and vanes,h=7,15,20,29,37 & 48 m M3:Sonic, cup and vanes, h=6, 7, 15,18, 20, 29, 37, 43,45 & 48 m
Periods	May 1994 – August 1995
Measurements	1) 5Hz cup, 2400 hours 2) 20 Hz 3D-sonic, 2400 hours 3) 30 min. statistics of wind (mean, stdev, min & max); 48700 hours (= 6 years)
Comments	Time series of structural loads from 2 turbines and power from all turbines are available.
Purpose	Danish offshore wind farm measurement program
Contact person	Kurt S. Hansen/MEK.DTU
Data storage	http://www.winddata.com/; site=vindeby
Data owner	DONG Energy & RISØ.DTU
Data accessibility	No restrictions on wind measurements

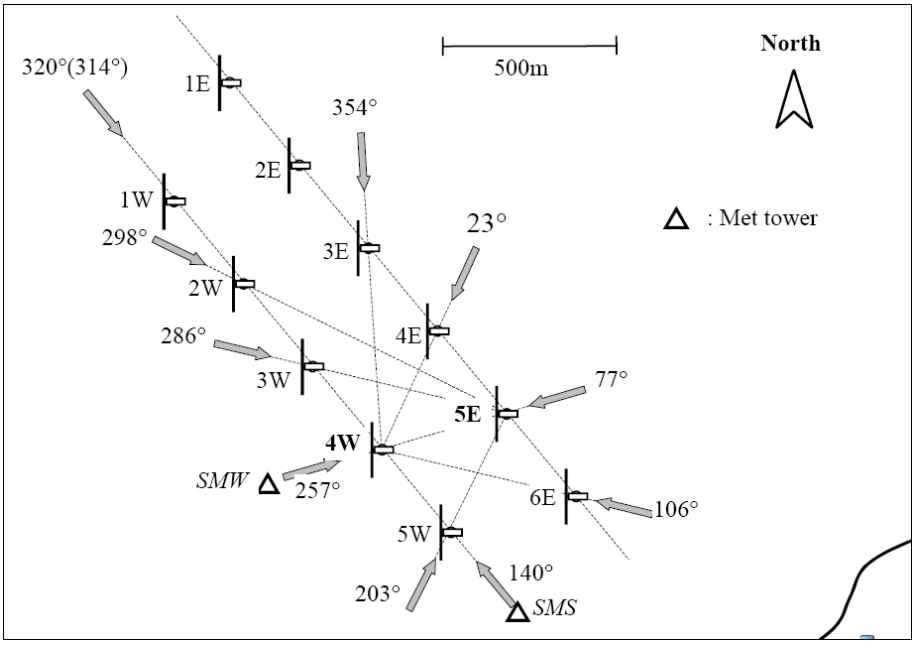

Figure 7: Site layout for the Vindeby offshore wind farm (DK) consisting of 11 wind turbines and offshore masts (SMW & SMS) and 1 onshore masts (LM - outside the map), [4]& [5].

2.8 Bockstigen, Offshore, SE

Site	Bockstigen offshore wind farm, Gotland, SE
Wind turbine(s)	5 x WindWorld 500 kW, h=41.5 m (FS,SC)
Wind turbine diameter	37 m
Mast	1 x offshore mast, h= 50 m
Spacing (wt => wt)	5 – 14 x D
Instrumentation	Cup and vanes, h=9, 22, 37 & 40 m
Periods	Nov. 2000 – Jan. 2001 & Sep. 2004
Measurements	1Hz cup & vane, appr. 350 hours 17Hz structural loads & power from one turbine
Comments	Further time series of structural loads and power measurements are available from TG. Description of the wind farm and the measurement setup is given in [6].
Purpose	Swedish offshore wind farm measurement program [6]
Contact persons	Kurt S. Hansen/MEK DTU or Hans Ganander/TG
Data storage	http://www.winddata.com/; site=bockstigen
Data owner	Teknikgruppen AB (SE)
Data accessibility	No restrictions

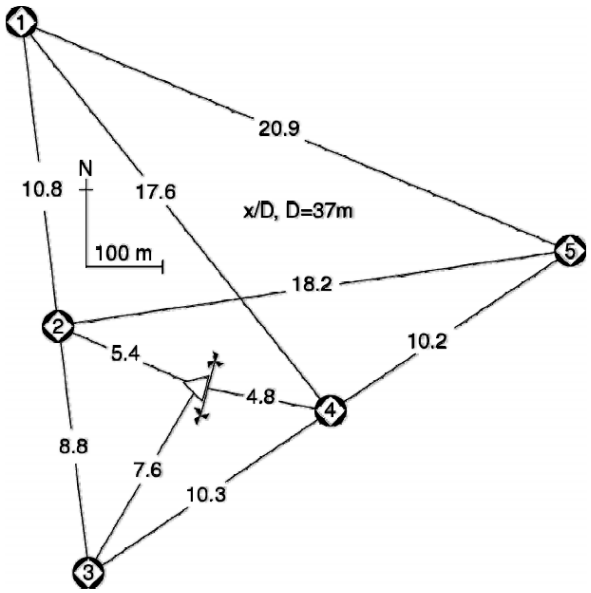

Figure 8: Layout of the Bockstigen(SE) offshore wind farm with 5 wind turbines and 1 mast. The spacing is in number of diameters, D=37m from [6].

2.8 Nysted, Offshore, DK

Site	Nysted offshore wind farm, DK
Wind turbine(s)	72 x Bonus 2.3MW, h=70 m (2xFS;ASC)
Wind turbine diameter	84 m
Masts	5 x offshore masts, h= 70 m
Spacing (wt => wt)	5.7D / 10.3D / 10.9D & 12.6D
Instrumentation	Cup and vanes, h=10 - 70 m
Period	2004-2007
Measurements	cup & vane, h=10-70 m on 5 masts, Power from 72 wind turbines; appr. 20.000 hours
Comments	1 Hz time series of wind speeds and power measurements; appr. 7.000 hours.
Purpose	Offshore wind farm measurement program
Contact person(s)	Kurt S. Hansen/MEK.DTU Leo Jensen/DONG Energy
Data storage	Database at MEK.DTU
Data owner	DONG Energy & EON
Data accessibility	Restricted to EU-UPWIND and EU-Topfarm

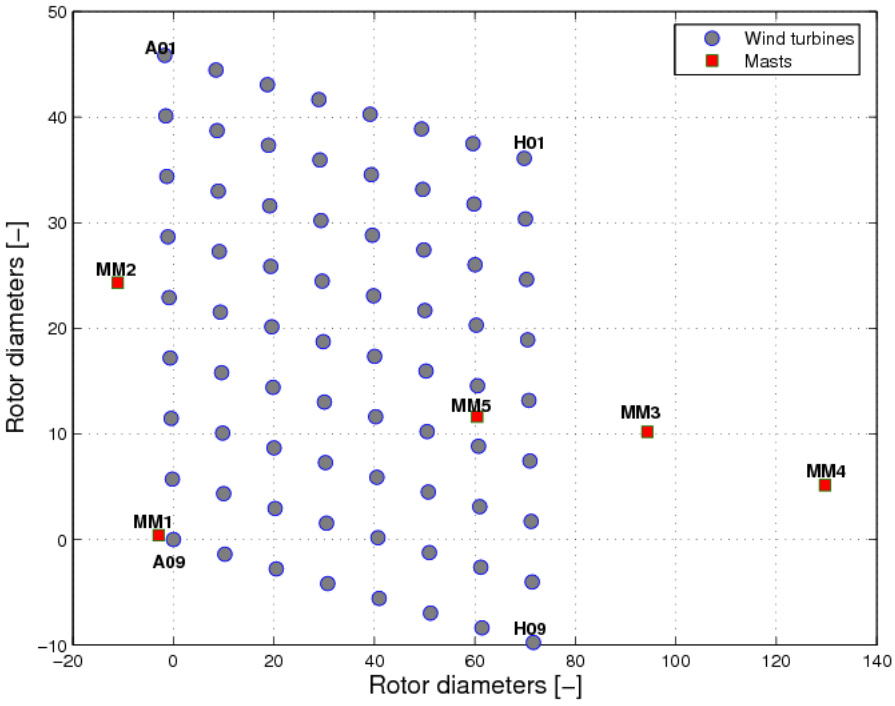

Figure 9: Site layout of the Nysted offshore wind farm, with a spacing unit; D= 84m.

2.9 OWEZ, Offshore, NL

Site	Offshore Windpark Egmond an Zee (NoordZee / OWEZ)
Wind turbine(s)	36 x VESTAS V90 3MW, h=70 m (VS,PC)
Wind turbine diameter	90 m
Mast	offshore mast, h= 116 m
Spacing (wt => wt)	7.2D / 11.1D / 13.2D / 18.D
Instrumentation	3D sonics, cup and vanes, h=21,70 & 116m
Periods	2006-2007
Measurements	1) Sonic, cup & vane, h=21, 70 & 116 m – 10 minute statistics, appr.17.500 hours. 2) Power from 36 turbines as SCADA data; appr. 15.400 hours. 3) Structural loads from two turbines, 25 Hz; appr 6.700 hours.
Comments	Time series of power and structural loads including tower loads are available.
Purpose	Dutch offshore wind farm measurement program
Contact person(s)	Kurt S. Hansen/MEK.DTU or Dick Veldkamp/Vestas Wind Systems, NL
Data storage	Database at MEK.DTU
Data owner	NoordzeeWind B.V., NL
Data accessibility	Restricted to the EU-Topfarm project

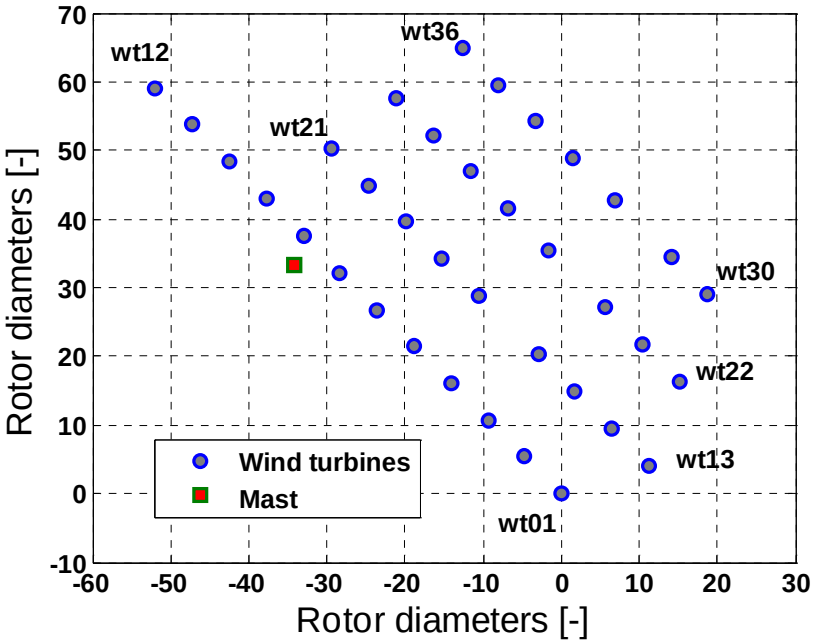

Figure 10: Site layout for NoordZee (OWEZ, NL) wind farm consisting of 36 wind turbines and one mast.

3 Wind turbine – wind turbine interaction

3.1 Middelgrunden, Offshore, DK

Site	Middelgrunden offshore wind farm, Copenhagen
Wind turbine	Bonus 2MW, h=64m (FS,SC)
Wind turbine diameter	76 m
Mast	n.a.
Spacing	2.4 D
Instrumentation	SCADA channels e.g. power, nacelle speed
Period	2001-2004
Measurements	10 minute statistics
Comments	Only SCADA data is available
Purpose	Data have been recorded as SCADA data
Contact person	Kurt S.Hansen / MEK.DTU
Data storage	Database at MEK.DTU
Data owner	DONG Energy & Middelgrundens vindmølle laug.
Data accessibility	No restrictions

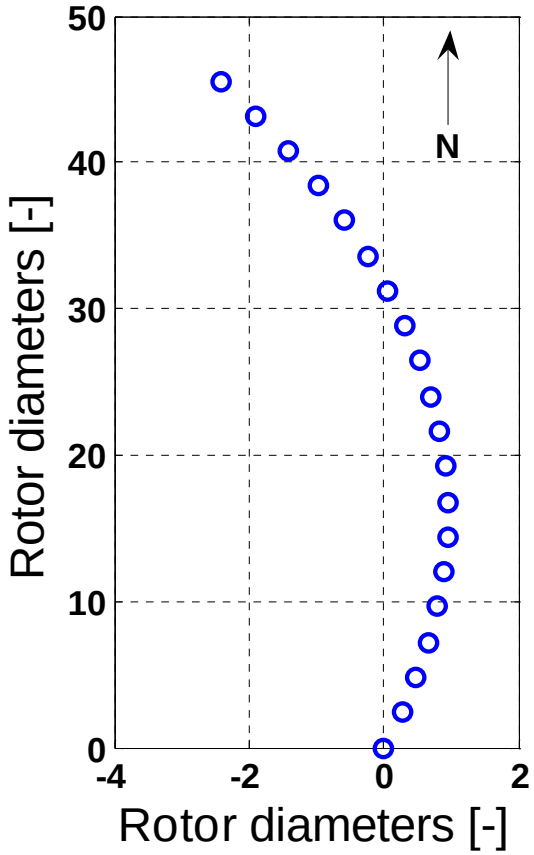

Figure 11: Layout of the Middelgrunden wind farm, with a 2.4D spacing.

3.2 Horns Rev, Offshore, DK

Site	Horns Rev, Offshore, Esbjerg
Wind turbine	Vestas, 80 x V80, h=70m (=160 MW) (VS,PC)
Wind turbine diameter	80 m
Masts	M2: 62 m & M6,M7: 70 m
Spacing	7D, 9.4D & 10.4D
Instrumentation	Cup & vanes, h=15,30,45,62 & 70m
Periods	2005-2008
Measurements	1) 10 min. statistics for wind, WT power & WT operational statistics (2005). 2) 10 min. statistics for power & WT operational statistics (2006-2008). 3) 1 s. records from wind farm (power, yp) 4) M2:20 Hz 3D-sonic, h=50 m 5) Structural loads from wind turbine #14,
Comments	SCADA data from wind farm
Purpose	Flow analysis in wind farms
Contact persons	Kurt S. Hansen/DTU MEK or Leo Jensen/DONG Energy
Data storage	Database at DTU MEK
Data owner	Vattenfall AB & DONG Energy A/S.
Data accessibility	Restricted to EU-UPWIND & EU TOPFARM

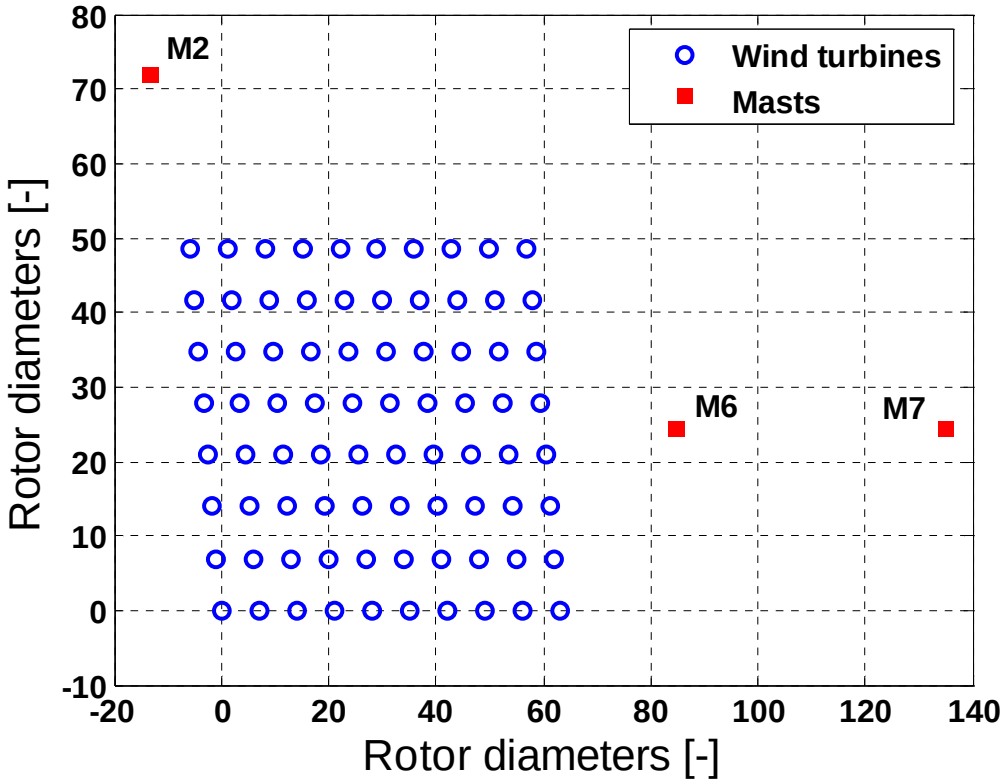

Figure 12: Layout of the Horns Rev wind farm including the location of 3 masts.

3.3 Nysted, offshore, DK

Site	Nysted offshore wind farm, DK
Wind turbine(s)	72 x Bonus 2.3MW, h=70 m (2xFS,ASC)
Wind turbine diameter	84 m
Masts	5 x offshore masts, h= 70 m
Spacing (wt => wt)	5.7D / 10.3D / 10.9D & 12.6D
Instrumentation	Cup and vanes, h=10 - 70 m
Period	2004-2007
Measurements	cup & vane, h=10-70 m on 5 masts, Power from 72 wind turbines; appr. 20.000 hours
Comments	Time series of wind speeds and power measurements, 1Hz; appr. 7.000 hours.
Purpose	Offshore wind farm measurement program
Contact persons	Kurt S. Hansen/DTU MEK or Leo Jensen/DONG Energy
Data storage	Database at MEK.DTU
Data owner	DONG Energy A/S & EON
Data accessibility	Restricted to EU-UPWIND and EU-Topfarm

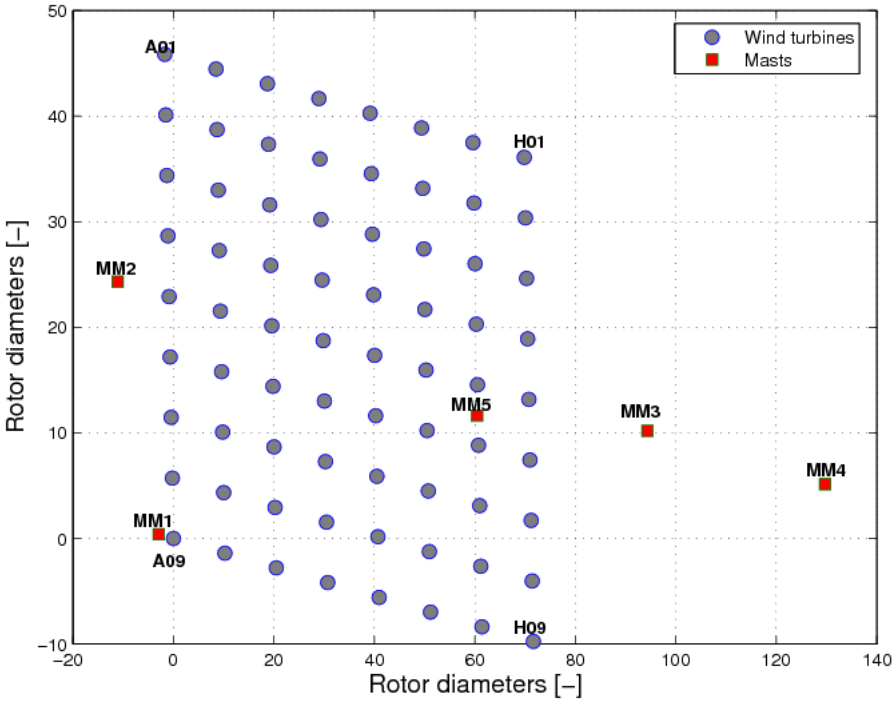

Figure 13: Site layout of the Nysted offshore wind farm, with a spacing unit; D= 84m.

3.4 Nørrekær Enge, Onshore wind farm, DK

Site	Nørrekær Enge, Onshore wind farm,DK (wind farm has been removed in 2009).
Wind turbine	Nordtank NTK 330 kW, h=31 m (FS,SC)
Wind turbine diameter	28 m
Masts	M1,M2: 58 m
Spacing	6.3D, 8.2D & 10.7D
Instrumentation	Cup and vanes: 3, 10, 23 31, 44 & 58 m & 3D sonics
Periods	Mar 1992 - June 1993
Measurements	10 min. statistics (mean, std) from SCADA system; 1 Hz wind speed measurements and 20 Hz 3D sonic speed & structural loads in 2 turbines
Comments	Several reports have been published [9]
Purpose	Flow analysis in wind farms
Contact person	Kurt S. Hansen/MEK.DTU
Data storage	http://www.winddata.com/; site=norre
Data owner	RISØ.DTU
Data accessibility	No restrictions

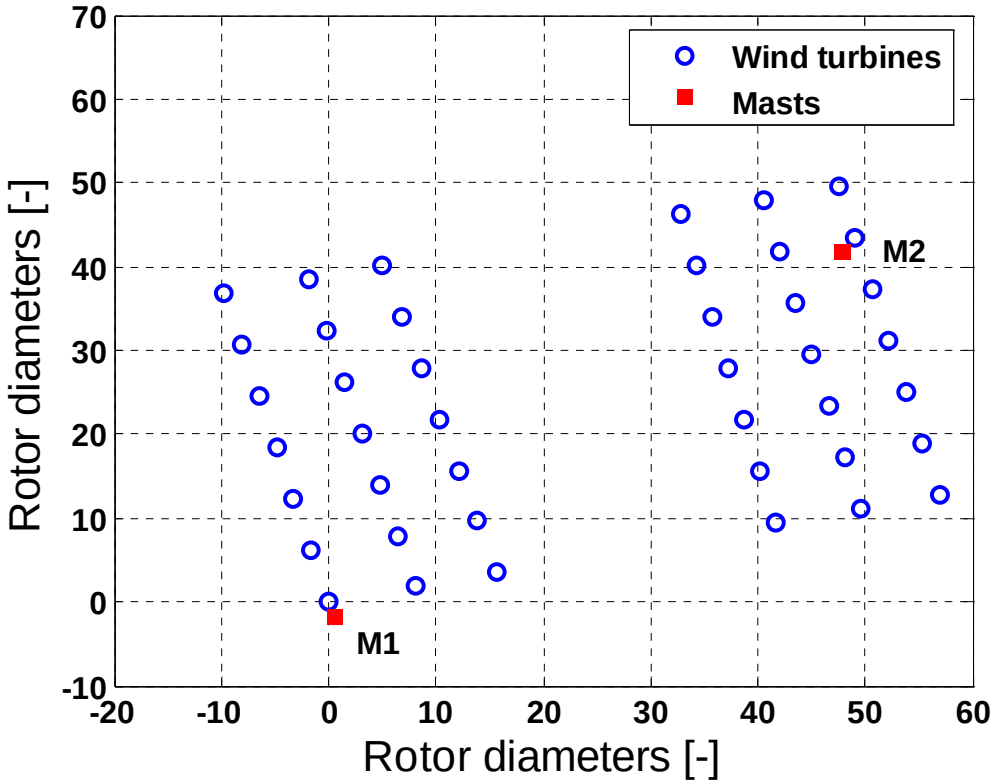

Figure 14: Layout of the Nørrekær Enge onshore wind farm including 2 masts.

3.5 Delabole, Onshore wind farm, UK

Site	Delabole onshore wind farm, UK
Wind turbine	10 x Vestas WD34; 400 kW, h=32 m (FS,PC)
Wind turbine diameter	38.8 m
Masts	h=33 & 44 m
Spacing	6.1D, 6.8D, 7.2D &7.6D
Instrumentation	Cup and vanes: 3, 10, 23 31, 44 & 58 m
Periods	April 1993 – March 1994
Measurements	10 min. statistics (mean, std) from SCADA system and 2 masts.
Comments	Measurements project is presented in [8]
Purpose	Technical performance analysis of wind turbines in array [8].
Contact person	Kurt S. Hansen / MEK.DTU
Data storage	http://www.winddata.com/; site=delabole
Data owner	ETSU & DTI, UK
Data accessibility	No restrictions

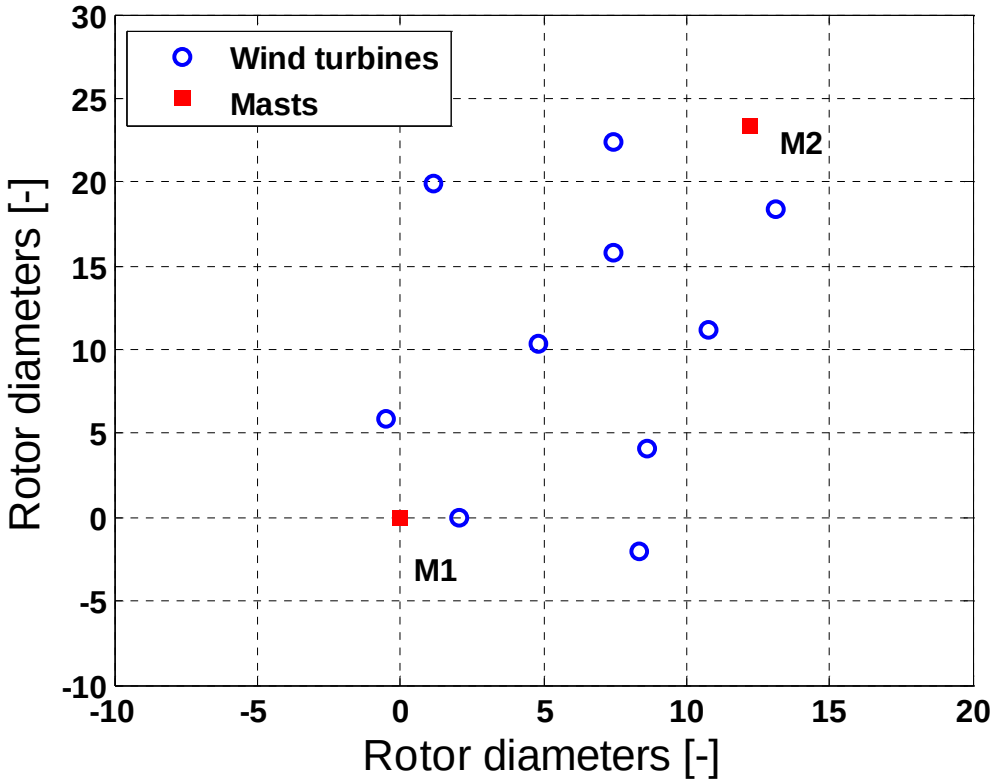

Figure 15: Site layout of the Delabole wind farm including 2 masts.

3.6 NoordZee, Dutch offshore wind farm, NL

Site	Offshore Windpark Egmond an Zee (NoordZee / OWEZ)
Wind turbine(s)	36 x VESTAS V90 3MW, h=70 m (VS,PC)
Wind turbine diameter	90 m
Masts	offshore mast, h= 116 m
Spacing (wt => wt)	7.2D / 11.1D / 13.2D / 18.D
Instrumentation	SCADA data from 36 wind turbines
Periods	2006-2007
Measurements	Power from 36 turbines as SCADA data; appr. 15.400 hours.
Comments	SCADA data is merged with 10 minute statistics from the mast.
Purpose	Dutch offshore wind farm measurement program
Contact person(s)	Kurt S. Hansen/DTU & Dick Veldkamp/Vestas Wind Systems, NL
Data storage	Database at MEK.DTU
Data owner	NoordzeeWind B.V., NL
Data accessibility	Restricted to the EU-Topfarm project

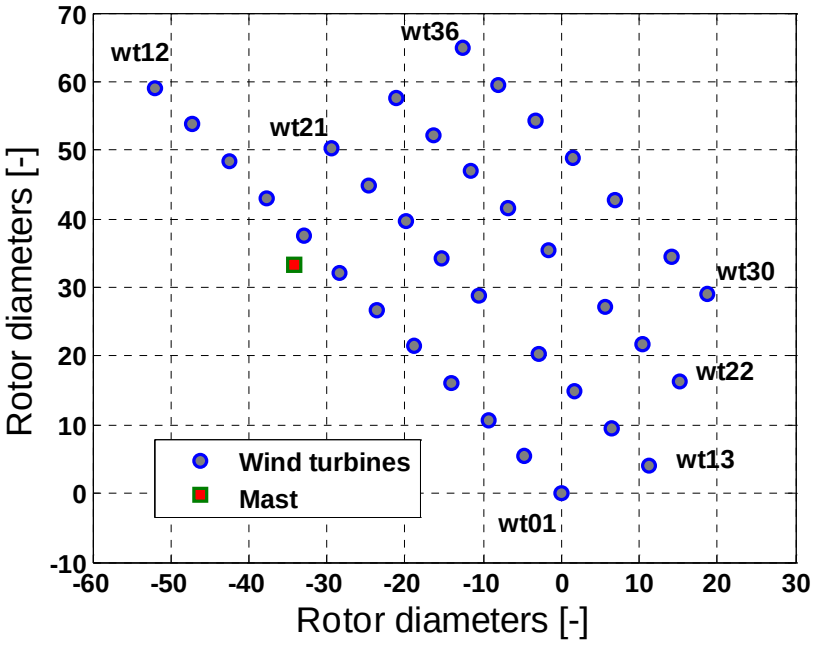

Figure 16: Site layout for NoordZee (OWEZ, NL) wind farm consisting of 36 wind turbines and one mast.

3.7 NM80, Tjæreborg, DK in 2003

Site	Tjæreborg wind farm in Tjæreborg Enge, Esbjerg
Wind turbine	NM80 2.5 MW, hub=57m (VS,PC).
Wind turbine diameter	80 m
Mast	57 m
Spacing; wt-wt	3D, 3.9D, 4.6D, 5.6D, 7D,…
Spacing; wt-mast	2.5D
Instrumentation	-sonic, cups and vanes on 57 m mast -structural wind turbine loads -rotating blade mounted 5-hole pitot tube
Period	Oct-Nov 2003
Measurements	1800 time series of wind speed and structural loads are available.
Comments	Reported in [10;11]
Purpose	Inflow analysis using pitot tubes
Contact person	Helge A. Madsen /RISØ.DTU
Data storage	Internal Risø dataserver / RISØ.DTU
Data owner	RISØ.DTU
Data accessibility	Restricted

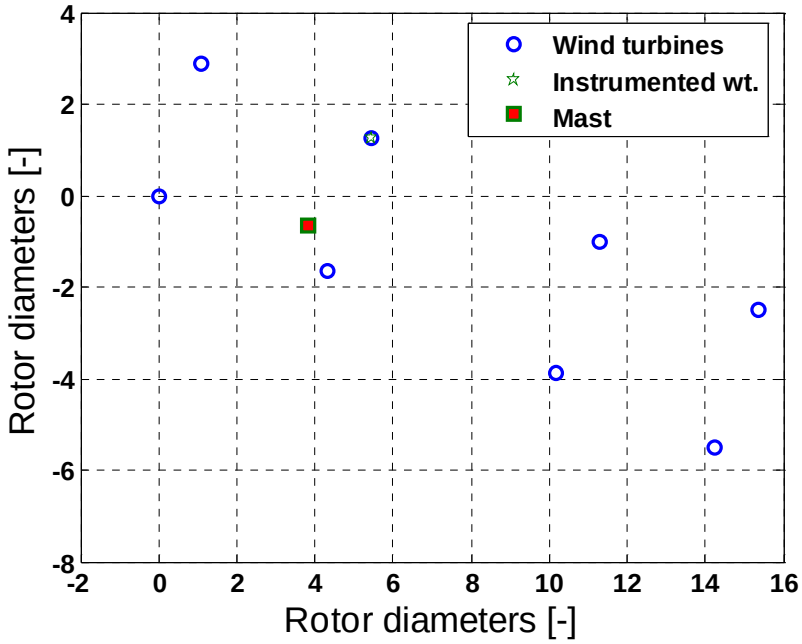

Figure 17: Site layout for the Tjæreborg wind farm, 2003

3.8 NM80, Tjæreborg, DK in 2009

Site	Tjæreborg wind farm in Tjæreborg Enge, Esbjerg
Wind turbine (s)	NM80 2.5 MW (VS,PC), hub=57m 5 x NM80+3xV80/V90 ≈ 20.5MW
Wind turbine diameter	80 m
Mast	93 m
Spacing; wt-wt	3D, 3.9D, 4.6D, 5.6D, 7D,… (normalized with D=80m)
Instrumentation	- SCADA data from 8 wind turbines - sonic, cups and vanes on 93 m mast
Period	Spring 2009
Measurements	Time series of wind speeds and SCADA data from all turbines
Comments	Ongoing measurement program
Purpose	Wake flow analysis
Contact person	Kurt S. Hansen /MEK.DTU
Data storage	Internal dataserver / MEK.DTU
Data owner	RISØ.DTU
Data accessibility	Restricted to the EU-Topfarm project

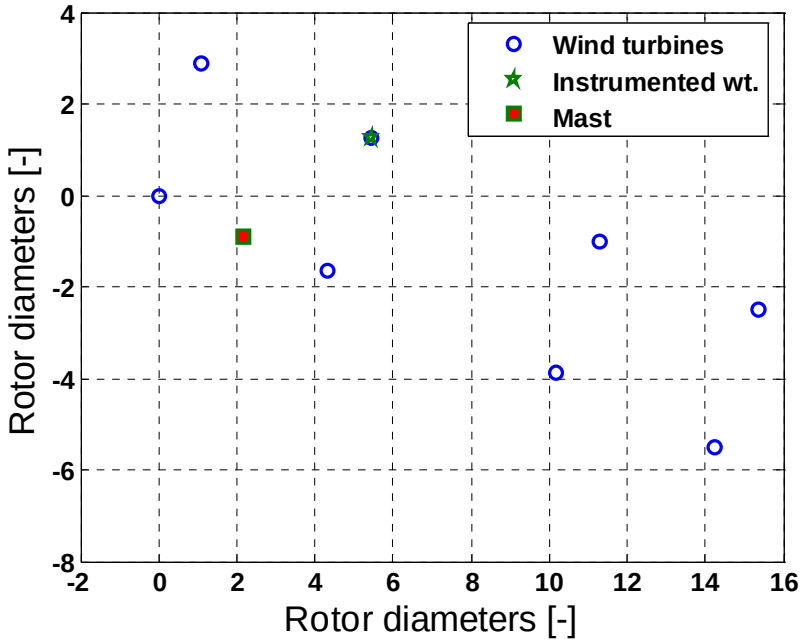

Figure 18: Site layout for the Tjæreborg wind farm, 2009.

3.9 ECN research wind farm, NL

Site	ECN test site in flat Polder land, NL
Wind turbine	5 x N80; 2.5 MW (VS,PC), hub=80m
Wind turbine diameter	80 m
Mast	108 m
Spacing; wt-wt	3.8D
Instrumentation	-sonic, cups and vanes on 52,80 & 108 m -structural wind turbine loads -SCADA data
Period	2005 - 2008
Measurements	Time series and SCADA data of power and wind speeds
Comments	Wake directions: EAST (very low turbulence) or WEST (low turbulence)
Purpose	Wind turbine wake and park analysis
Contact person	G.Schepers /ECN.NL
Data storage	Internal dataserver / ECN.NL
Data owner	ECN NL
Data accessibility	Restricted to EU-UPWIND

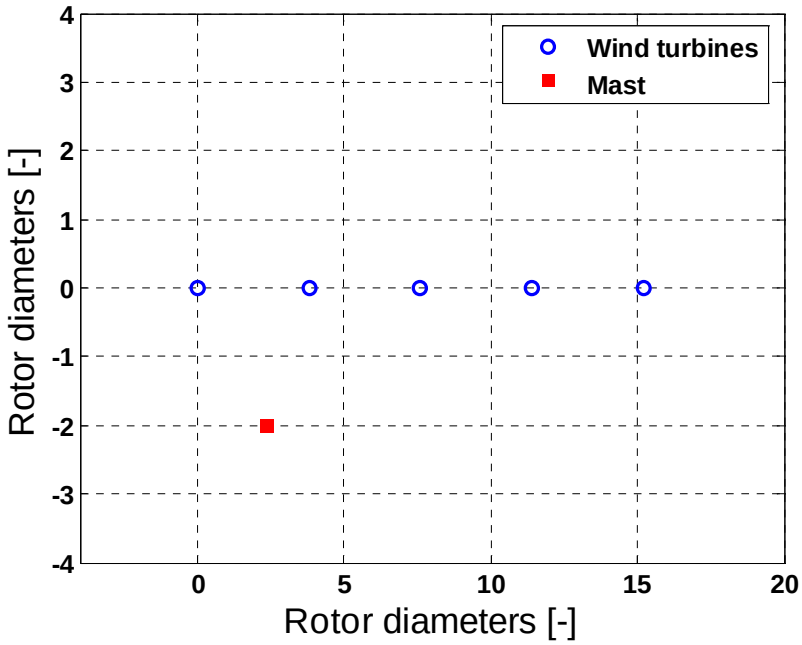

Figure 19: ECN research wind farm including mast.

4 Wind turbine – direct wake measurement

4.1 Tellus wake measurements

Site	Risø DTU Campus, Roskilde.
Wind turbine	Tellus 95 kW (FS,SC), hub=29m
Wind turbine diameter	19 m
Mast	33m mast, 36 m in westerly direction.
Instrumentation	Horizontal mounted LIDAR operating with a frequency of 136 Hz.
Measurements	1) Line scanning and deep line scanning, 136 Hz with a focus length of: 1D, 4D, 6.8D & 9.3D 2) Single plane scanning (PAN=±35º; TILT=±15º) – wake deficit analysis. 3) Multi-plane scanning towards Nordtank turbine (< 1Hz/plane)
Comments	Wake measurements have been analyzed for: 1) One dimensional Scanning [12,13]; 2) Single-plane measurements have been analyzed and presented [14],
Periods	September – December 2005, April - May 2006 & June – July 2007
Purpose	Dynamic wake meandering analysis
Contact persons	Ferhat Bingöl & Gunner Chr. Larsen / RISØ.DTU
Data storage	Internal dataserver at Risø DTU
Data owner	RISØ.DTU
Data accessibility	Restricted to EU-TOPFARM

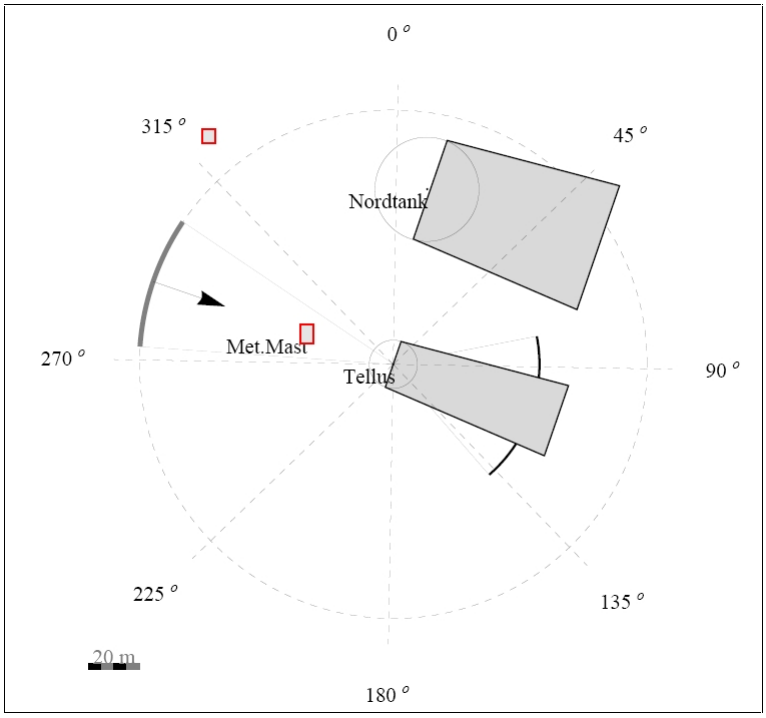

Figure 20: Site layout for the Tellus experiment, viz. in [13].

4.2 NM80 wake measurements, Tjæreborg

Site	Tjæreborg wind farm in Tjæreborg Enge, Esbjerg
Wind turbine	NM80 2.5 MW (VS,PC), hub=57m
Wind turbine diameter	80 m
Mast	93 m
Spacing; wt-wt	3D, 3.9D, 4.6D, 5.6D, 7D,… (normalized with D=80m)
Instrumentation	- SCADA data from 8 wind turbines, Figure 18. - sonic, cups and vanes on 93 m mast - Horizontal LiDAR mounted for measuring the wake properties, Figure 21.
Period	Jan. – May 2009
Measurements	Time series of wind speeds, SCADA data from all turbines and 349 Hz single plane wake measurements with a focus length of either 40, 80, 120, 160 or 200m 1) Single wake situations: 400 hours 2) Multiple wake situations: 300 hours
Comments	Preliminary wake analysis has been presented in [15]
Purpose	Dynamic wake field analysis
Contact person	Kurt S. Hansen / MEK.DTU
Data storage	Internal dataserver / MEK.DTU
Data owner	RISØ.DTU
Data accessibility	Restricted to the EU-Topfarm project

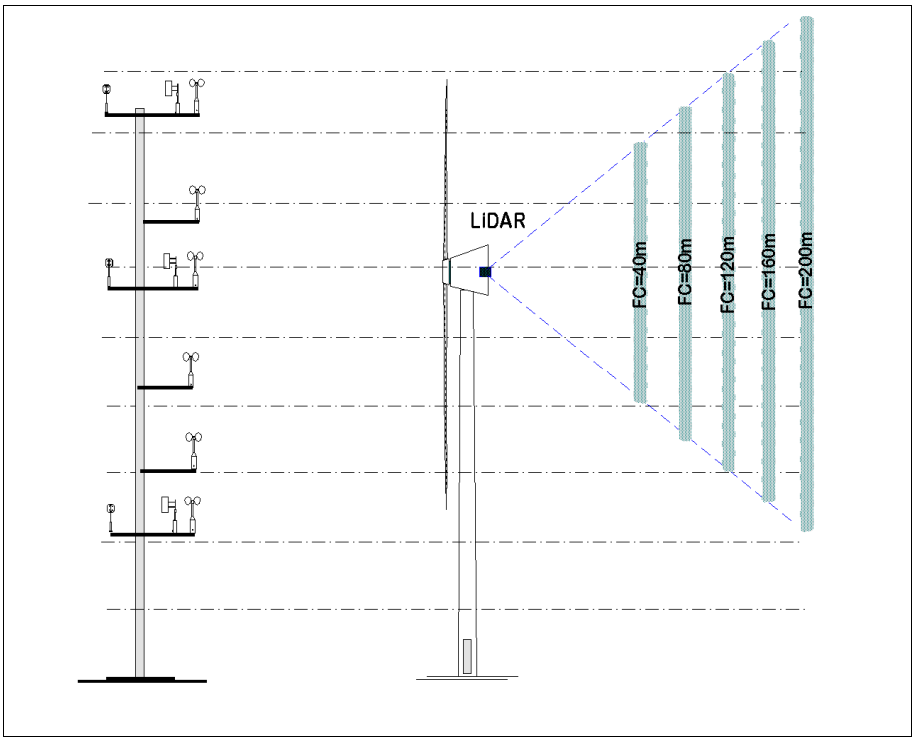

Figure 21: Wake measurement setup on the NM80 wind turbine with 5 different focus lengths ranging from 40 to 200 m.

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We would like to acknowledge **DONG Energy A/S** and **E.On Sweden** for data from the Nysted wind farm.

NoordZee
We would like to acknowledge **NoordzeeWind B.V**. **The Netherlands** for data from the OWEZ offshore wind farm.

Annex A: Database of Wind Characteristics

www.winddata.com
An Internet database with tutorials, documentation of the database structure and the database contents. This address enables access to the data query system and the ftp storage [17;18;19].

Background
Vast amounts of wind data have been measured at many different locations. Of the thousands of hours of time series collected, only a tiny proportion are available for use by the wind turbine and wind engineering communities.

Data in the database
The database contains four different categories of data: time series of wind characteristics, time series of wind turbine responses, wind resource data and wind farm data, however, with the main emphasis on the first category. A wide variety of wind climates and terrain types are represented together with significant amounts of wind field time series, measured in wakes of wind turbines. The time series are stored in a common file format, with time resolution ranging between 1 and 40 Hz. The time series are intended for design and simulation studies. The wind resource data are stored as 10-minute statistics. Emphasis has been given to ensure a high level of documentation of the measurement setups. Furthermore, a search and data selection system has been developed that fully utilizes the interactive nature of the WWW. Tools for visualizing and analyzing time series are included on the web-server, [17;18;19].

Geographical Coverage
The database contains wind field measurements from 80 different sites in Europe, Egypt, USA and Japan, ranging from offshore to complex terrain. The coverage has been extended, with time series primarily from high-wind sites and offshore locations. Medio 2009 the database contains more than 196,000 hours of wind speed time series, more than 6,500 hours of wind turbine response measurements, more than 1,100,000 hours of wind resource measurements and more than 19,000 hours of wind farm measurements.

Implementation
In order to implement a suitable search system, we have constructed a database for detailed registration of field measurements, ranging in scope from the administrative level down to the mounting details of individual sensors. The quality of the wind data are assessed according to a number of criteria such as presence of spikes, signal noise, trends, etc. Subsequently, data are indexed using a variety of parameters, including conventional statistics, extremes, turbulence intensity, gusts, accelerations and wind shear. All indexed values are available online. Furthermore, Paradox and MS-Access tables with site-specific statistics are available for post-processing analysis.

Online facilities

The online facilities, provided through the Internet, are:

- Access to fast-sampled wind field measurements (≥1Hz), 10-minute statistics, higher-order moments and extreme events.
- Access to fast-sampled (≥1 Hz) structural wind turbine measurements (bending moments, torque, electrical power, pitch settings).
- Access to resource data, in terms of slow-sampled (< 1 Hz) wind field measurements covering long periods [years].
- Access to wind farm measurements (SCADA data).
- Access to an appropriate documentation of the measurement setup and a site description.
- Access to a Wind Energy Document Database with wind energy related literature.

How to get time series

Use of the database online facilities including access to the ftp storage requires an online registration. With a user id all users can identify suitable time series and download these from the ftp-server for further analysis.

Contact information
Kurt Schaldemose Hansen,
Senior Scientist
DTU Mechanical Engineering
Technical University of Denmark
DK-2800 Lyngby
Denmark
Phone +45 45254318
Email ksh@mek.dtu.dk

Printed at
DTU Mechanical Engineering
Section of Fluid Mechanics
Technical University of
Nils Koppels Allé, Bld. 403
DK- 2800 Kgs. Lyngby
Denmark
Phone (+45) 45 25 43 00
Fax (+45) 45 88 43 25

www.mek.dtu.dk

DTU Mechanical Engineering
Section of Fluid Mechanics
Technical University of Denmark

Nils Koppels Allé, Bld. 403
DK- 2800 Kgs. Lyngby
Denmark
Phone (+45) 45 25 43 00
Fax (+45) 45 88 43 25

www.mek.dtu.dk