TR A6637

Vindkraft FoU Seminar – Fremtiden er offshore? 24. – 25. januar 2008

John Olav Tande

www.sintef.no

SINTEF Energiforskning AS

Februar 2008

Rapporten er utarbeidet i samarbeid med:

SINTEF

IFE

NTNU
Det skapende universitet

IEEE
Norway Section

cigré
The Norwegian National
Committee of CIGRÉ

TEKNISK RAPPORT

SINTEF

SINTEF Energiforskning AS

Postadresse: 7465 Trondheim
Resepsjon: Sem Sælands vei 11
Telefon: 73 59 72 00
Telefaks: 73 59 72 50

www.energy.sintef.no

Foretaksregisteret:
NO 939 350 675 MVA

SAK/OPPGAVE (tittel)

Vindkraft FoU Seminar – fremtiden er offshore?

SAKSBEARBEIDER(E)

John Olav Tande

OPPDRAGSGIVER(E)

TR NR.	DATO	OPPDRAGSGIVER(E)S REF.	PROSJEKTNR.	
TR A6637	2008-02-04		12X27801	
EL. ARKIVKODE	RAPPORTTYPE	PROSJEKTANSVARLIG (NAVN, SIGN.)	GRADERING	
080204RHA152641		John Olav Tande	Åpen	
ISBN NR.		FORSKNINGSSJEF (NAVN, SIGN.)	OPPLAG	SIDER
978-82-594-3363-3		Petter Støa	10	155
AVDELING		BESØKSADRESSE	LOKAL TELEFAKS	
SINTEF Energiforskning AS		Sem Sælands vei 11	73 59 72 50	

RESULTAT (sammendrag)

Denne rapporten gjengir presentasjoner fra Vindkraft FoU seminar 24-25 januar 2008 i Trondheim. Seminaret er en oppfølging på tilsvarende arrangert i 2004, 2005, 2006 og 2007, og er etablert som en viktig møteplass for alle norske vindkraftaktører. Følgende tema er presentert:

- Energi for fremtiden / Vindkraft i Norge
- Offshoreteknologi
- Offshore vindkraft som nasjonal satsning – Energirådet (paneldebatt)
- TradeWind – Transmission / Market
- Vindressurser
- Nettintegrasjon

Seminaret er arrangert av SINTEF, IFE og NTNU i fellesskap ved John Olav Tande (SINTEF Energiforskning), Per Finden (IFE/NTNU), Erik Berge (Kjeller Vindteknikk), Geir Moe (NTNU), Terje Gjengedal (Statkraft/NTNU) og Tore Undeland (NTNU).

EGENVALGTE		

INNHOLDSFORTEGNELSE

Side

TradeWind – Transmission

TradeWind – Market

Vindressurser

Nettintegrasjon

SINTEF IFE NTNU

	Vindkraft FoU Seminar – fremtiden er offshore? 24-25 januar 2008 Royal Garden Hotell, Kjøpmannsgata 73, Trondheim	
	Torsdag 24 Januar	
09.00	Registrering & kaffe/mineralvann	
	Energi for Fremtiden - Ordstyrer: Prof. Terje Gjengedal, Statkraft/NTNU	
	Sted: Olav Tryggvasson	
10.00	Åpning og velkommen ved ordstyrer	
10.10	*Vindkraft - en av klimaløsningene;* Statssekretær Guri Størvold, OED	
10.30	*Politikk og folkelig aksept av vindkraft;* PhD Jøran Solli, NTNU	
10.50	*Vind og vannkraft – en gylden mulighet for norsk kraftbransje* Adm. dir. Lars Audun Fodstad, Sira-Kvina Kraftselskap	
11.10	*Offshore vindkraft – FoU aktivitet og foresight 2027* Seniorforsker John Olav Tande, SINTEF Energiforskning	
11.30	*The role of wind power in meeting the EU target of 20 % renewables by 2020 - TradeWind*, Technical Consultant Frans Van Hulle, EWEA	
12.00	Lunsj - Cicignon	
	Parallelle sesjoner	
13.00	**A1) Offshoreteknologi** **Sted: Olav Tryggvasson** Ordstyrer: Prof. Geir Moe, NTNU	**B1) TradeWind – Transmission** **Sted: Kristiansten** Session Chair: Frans Van Hulle, EWEA
15.00	Pause med lett servering	
15.20	**A2) Offshore vindkraft som nasjonal satsning – Energirådet** **Sted: Olav Tryggvasson** Ordstyrer: Tor-Odd Berntsen, sekretær for Energirådet	**B2) TradeWind – Market** **Sted: Kristiansten** Session Chair: Frans Van Hulle, EWEA
17.00	Pause	
18.00	Middag - Cicignon	
	Fredag 25 Januar	
	Parallelle sesjoner	
09.00	**C) Vindresurser** **Sted: Kristiansten** Ordstyrer: Erik Berge, Kjeller Vindteknikk	**D) Nettintegrasjon** **Sted: Haraldsalen** Ordstyrer: Prof. Tore Undeland, NTNU
11.10	Pause med lett servering	
	Vindkraft i Norge – Ordstyrer: Prof. Terje Gjengedal, Statkraft/NTNU **Sted: Haraldsalen**	
11.40	Innledning ved ordstyrer	
11.50	*ScanWind status- og veien videre*, Markedsdirektør Leiv Låte, ScanWind	
12.10	*Offshore vindkraft og elektrifisering av olje og gass installasjoner;* Marius Holm, Nestleder i Bellona	
12.30	*Statkraft's satsing på offshore vindkraft*, Petter Hersleth, Statkraft	
12.50	*Synergi offshore vind, olje og gass,* Sjefsforsker Finn Gunnar Nielsen, StatoilHydro	
13.20	Oppsummering ved ordstyrer	
13.30	Lunsj - Cicignon / Slutt	

SINTEF IFE NTNU

Torsdag 24 Januar	
	A1) Offshoreteknologi – FoU resultat **Sted: Olav Tryggvasson** Ordstyrer: Prof. Geir Moe, NTNU
13.00	Innledning ved ordstyrer
13.10	*Modellering av flytende vindkraftverk* Forskningssjef Frode Meling, MARINTEK
13.25	*Løsninger for et 100 meter vindturbinblad* PhD student Jørg Høyland, NTNU
13.35	*Individuell pitch av vindturbinblader* PhD student Fredrik Sandquist, NTNU
13.45	*Hydraulisk gir for vindkraftverk* Svein Kjetil Haugset, ChapDrive
14.05	*Stabilisering av flytende vindturbiner* PhD student Thomas Fuglseth, NTNU
14.15	*FEM Analysis of the NREL Phase VI Wind Turbine Blades* PhD student Haiyan Long, NTNU
14.25	*Simulering av flytende offshore vindturbin* Forsker Andreas Knauer, IFE
14.45	*Drift og vedlikeholdsoppfølging av vindkraftverk* Forsker Arnt O Eggen, SINTEF Energiforskning
15.00	*Pause med lett servering*
	A2) Offshore vindkraft som nasjonal satsning – Energirådet **Sted: Olav Tryggvasson** Ordstyrer: Tor-Odd Berntsen, sekretær for Energirådet
15.20	Innledning ved ordstyrer
15.30	*Paneldebatt med korte forberedte innlegg fra industri, FoU miljø og myndigheter som innspill til Energirådets analyse av den nasjonale verdien av offshore vindkraft* *Deltagere i panelet:* *Anne Strømmen Lycke, StatoilHydro* *Petter Støa, SINTEF Energiforskning* *Geir Moe, NTNU* *Knut Mollestad, Statkraft* *Kjartan Hauglum, Statnett* *Stig Svalheim, Lyse* *Jonathan Mechineau, OWEC Tower* *Energirådet er en møteplass for toppledere i energisektoren. Hensikten er å bidra til økonomisk og miljømessig verdigkapning i Norge og internasjonalt gjennom samarbeid, kompetanseutvikling og teknologiutvikling for internasjonalisering av energisektoren. Energirådet er oppnevnt av og rapporterer til statsråden i OED, som også leder møtene.*
16.50	Oppsummering ved ordstyrer
17.00	Pause
18.00	Middag - Tavern

Torsdag 24 Januar	
	B1) TradeWind – Transmission **Sted: Kristiansten** Session Chair: Frans Van Hulle, EWEA
13.00	Introduction by Session Chair
13.10	*The TradeWind power system simulation tool – modelling of the Nordel system* Senior research scientist Kjetil Uhlen, SINTEF Energy Research (Norway)
13.30	*Wind and grid scenarios for Nordel – first simulation results* Senior research scientist Bettina Lemström, VTT (FI)
13.50	*Grid connection perspectives of Kriegers Flak;* Senior Project Manager Göran Loman, Vattenfall AB (SE)
14.10	*The European Wind Integration Study EWIS* *Transmission planning in view of wind integration in NORDEL area* Fredrik Norlund, Svenska Kraftnät (SE)
14.40	Discussion and summary
15.00	Refreshments / Coffee break
	B2) TradeWind – Market **Sted: Kristiansten** Session Chair: Frans Van Hulle, EWEA
15.20	Introduction by Session Chair
15.30	*Market mechanisms facilitating efficient system operation with large amounts of wind power;* Achim Woyte, 3E (BE)
15.50	*Grid and market challenges with large scale wind development within Nordel;* Jan Bråten, Statnett (Norway)
16.20	*Development of wind farms in a market perspective*; Erlend Broli, Statkraft (Norway)
16.40	Discussion and summary
17.00	End of TradeWind seminar

SINTEF IFE NTNU

Fredag 25 Januar	
	C) Vindresurser **Sted: Kristiansten** Ordstyrer: Erik Berge, Kjeller Vindteknikk
09.00	Innledning ved ordstyrer
09.10	*Terrengets betydning for posisjonering av vindturbiner* Kjersti Røkenes, PhD student NTNU
09.30	*Ising på vindturbinene i Nygårdsfjellet vindpark,* Matthew Homola, Høgskolen i Narvik
09.50	*Vind- og iskart for Norge,* Øyvind Byrkjedal, KVT
10.10	*Offshore vindressurskartlegging*, Erik Berge, KVT
10.35	*Offshore turbulens – Erfaringer fra vindmålingene på Frøya,* Jørgen Løvseth, NTNU
11.00	Diskusjon og oppsummering
11.10	Pause med lett servering
11.40	Felles program
12.30	Lunsj - Cicignon / Slutt

Fredag 25 Januar	
	D) Nettintegrasjon **Sted: Haraldsalen** Ordstyrer: Prof. Tore Undeland, NTNU
09.00	Innledning ved ordstyrer
09.10	*SmartGenerator - utvikling av ny generatorteknologi for vindkraftverk* Prof. Robert Nielsen, NTNU
09.30	*Kabelteknologi for offshore vindkraft* Vegar Syrtveit Larsen, Avdelingsleder – Teknisk avdeling PEX kabler og utstyr, Nexans Norway
09.50	*HVDC Light for tilkobling av offshore vindparker* Peter Sandeberg, Lead Engineer Transmission Offshore Wind, ABB Grid System, Sverige
10.10	*Bruk av vannkraft til balansering av store menger offshore vindkraft* Forsker Thomas Trötscher, SINTEF Energiforskning
10.30	*Modellering av variabel hastighet vindturbiner for kraftsystemanalyse* Jarle Eek, PhD student NTNU
10.45	*Systemkrav til vindkraftverk,* Seniorforsker John Olav Tande, SINTEF Energiforsking
11.00	Diskusjon og oppsummering
11.10	Pause med lett servering
11.40	Felles program
12.30	Lunsj - Cicignon / Slutt

SINTEF

Vindkraft FoU Seminar – fremtiden er offshore?
24-25 januar 2008, Royal Garden Hotell, Kjøpmannsgata 73, Trondheim

Navn	Firma	Email
Sandeberg, Peter	ABB Grid Systems	peter.sandeberg@se.abb.com
Løvstad, Tommy	Agder Energi Produksjon	Tommy.Lovstad@ae.no
Rørholm, Niels Baden	Agder Energi Produksjon	nieror@ae.no
Skadal, Espen	Agder Energi Produksjon	Espen.skadal@ae.no
Stakkeland, Øyvind	Agder Energi Produksjon	oyvind.stakkeland@ae.no
Vogstad, Klaus	Agder Energi Produksjon	Klaus-Ole.Vogstad@ae.no
Woyte, Achim	3E	achim.woyte@3E.be
Holm, Marius	Bellona	
Hernborg, Gunnar	BKK Rådgiving AS	Gunnar.hernborg@bkk.no
Håvik, Astrid	BKK Rådgiving AS	Astrid.havik@bkk.no
Matre, Jostein	BKK Rådgiving AS	Jostein.matre@bkk.no
Haugset, Svein Kjetil	ChapDrive	
Kreutzkamp, Paul	Dena	
Finne, Jan	Dong Energy	
Haavik, Henriette R.	EBL Kompetanse	hha@ebl-kompetanse.no
Berntsen, Tor-Odd	Energirådet	tor-odd.berntsen@proevolve.no
Olderheim, Harald	Energy Future Invest AS	harald@energyfutureinvest.com
Jakobsen, Tomas Frithjof	Engineering Data Resources	tomas.jakobsen@edr.no
Skjølsvik, Kjell Olav	Enova SF	Kjell.olav.skjolsvik@enova.no
Rodrigues, Glória	EWEA	Gloria.Rodrigues@ewea.org
van Hulle, Frans	EWEA	frans@ewea.org
Rasmussen, Helge	HighComp AS	hr@bokn-plast.no
Finden, Per	IFE	per.finden@ife.no
Knauer, Andreas	IFE	andreas.knauer@ife.no
Hagen, Espen	Institutt for energiteknikk	espen.hagen@ife.no
Homola, Matthew	Høgskolen i Narvik	
Haavik, Inger Kallevik	Karmøy kommune	ikh@karmoy.kommune.no
Berge, Erik	Kjeller Vindteknikk AS	erik.berge@ife.no
Byrkjedal, Øyvind	Kjeller Vindteknikk AS	Oyvind.byrkjedal@vindteknikk.no
Undheim, Ove	Kjeller Vindteknikk AS	ove.undheim@vindteknikk.no
Bjordal, Håvard Nagell	Lyse Produksjon AS	havard.bjordal@lyse.no
Svalheim, Stig	Lyse Produksjon AS	Stig.svalheim@lyse.no
Fylling, Ivar	MARINTEK	
Strømberg, Håkon	Nemo Enginerring AS	stromberg@nemo-engineering.no
Larsen, Vegar Syrtveit	Nexans Norway	
Forsaa, Brynjar	Nordkraft AS	bf@narvik-energi.no
Jensen, Åge	Nordkraft AS	aaj@narvik-energi.no
Hanssen, Ulf R.	Nordkraft Vind AS	urh@narvik-energi.no
Wiik, Tore	Nordkraft Vind AS	tw@Narvik-Energi.no
Gether, Harald	NordNorsk Havkraft	
Bingen, Jon	NORISS	jon.bingen@noriss.no
Ruud, Jan W.	Norsk VindPro AS	jan.ruud@vindpro.no
Bazilchuk, Nancy	NorwayExports	nancy.bazilchuk@gmail.com
Galaaen, Øystein Schmidt	Norwea	galaaen@norwea.no
Dalbu, Helge	NTE	helge.dalbu@nte.no
Eek, Jarle	NTNU	jarle.eek@elkraft.ntnu.no

SINTEF

Fuglseth, Thomas	NTNU	
Hustad, Johan	NTNU	Johan.hustad@ntnu.no
Høyland, Jørg	NTNU	jorg.hoyland@ntnu.no
Long, Haiyan	NTNU	
Lægreid, Astrid	NTNU	astrid.lagreid@ntnu.no
Løvseth, Jørgen	NTNU	jorgen.lovseth@ntnu.no
Moe, Geir	NTNU	
Nilssen, Robert	NTNU	
Røkenes, Kjersti	NTNU	kjersti.rokenes@ntnu.no
Sandquist, Fredrik	NTNU	
Shengtie, Wang	NTNU	Wang.Shengtie@elkraft.ntnu.no
Solli, Jøran	NTNU	
Undeland, Tore	NTNU	Tore.Undeland@elkraft.ntnu.no
Fahl, Pascal	NTNU (student)	pascal.fahl@gmx.de
Fønstelien, Olav J.	NTNU (student)	olavjako@stud.ntnu.no
Husum, Eirik Mathias	NTNU (student)	eirikmat@stud.ntnu.no
Olsen, Pål Keim	NTNU (student)	palkeim@stud.ntnu.no
Svendsen, Trine	NTNU (student)	trinesv@stud.ntnu.no
Groussard, Mathieu	NVE	gmmg@nve.no
Hofstad, Knut	NVE	kho@nve.no
Knagenhjelm, Marius	OED	Marius.Knagenhjelm@oed.dep.no
Størvold, Guri	OED	
Hestevik, Svein	One Earth Technology Group	Svein.hestevik@cgholding.no
Mechineau, Jonathan	Owec Tower	jonathan_mechineau@yahoo.fr
Fredriksen, Karl Erik	Parker Scanrope	
Bekkelund, Per Halvor	Rambøll Norge AS	per.halvor.bekkelund@ramboll.no
Skorpen, Per Ove	Rambøll Norge AS	Per.ove.skorpen@ramboll.no
Berg, Jon Trygve	Sarsia Seed management AS	jon@sarsia.com
Låte, Leiv	ScanWind	
Kvernevik, Arnar	SFE Produksjon	Arnar.Kvernevik@sfe.no
Sætre, Hans Jørgen	Shell Technology Norway	Hansjorgen.satre@shell.com
Røset, Einar	Siemens AS	einar.roset@siemens.com
Skånøy, Thomas	Siemens AS	thomas.skaanoey@siemens.com
Eggen, Arnt Ove	SINTEF Energiforskning	arnt.o.eggen@sintef.no
Johansson, Emil	SINTEF Energiforskning	emil.johansson@sintef.no
Samdal, Knut	SINTEF Energiforskning	knut.samdal@sintef.no
Solvang, Tarjei	SINTEF Energiforskning	Tarjei.solvang@sintef.no
Støa, Petter	SINTEF Energiforskning	Petter.Stoa@sintef.no
Tande, John Olav	SINTEF Energiforskning	john.o.tande@sintef.no
Trötscher, Thomas	SINTEF Energiforskning	thomas.troetscher@sintef.no
Uhlen, Kjetil	SINTEF Energiforskning	kjetil.uhlen@sintef.no
Armada, Sergio	SINTEF Materialer og kjemi	sergio.armada@sintef.no
Bjørgum, Astrid	SINTEF Materialer og kjemi	astrid.bjorgum@sintef.no
Onsøien, Morten	SINTEF Materialer og kjemi	morten.i.onsoien@sintef.no
Fodstad, Lars Audun	Sira-Kvina Kraftselskap	
Fokkens, Andreas	SmartMotor AS	andreas@smartmotor.no
Skare, Eirik	SmartMotor AS	Eirik.skare@glendimplex.no
Øvrebø, Sigurd	SmartMotor AS	sigurd@smartmotor.no
Broli, Erlend	Statkraft	
Gjengedal, Terje	Statkraft	Terje.Gjengedal@statkraft.com
Hersleth, Petter	Statkraft	Petter.Hersleth@statkraft.com

SINTEF

Mollestad, Knut	Statkraft	Knut.mollestad@statkraft.com
Rognlien, Linn	Statkraft	Linn.Rognlien@statkraft.com
Henriksen, Morten	Statkraft Development	Morten.henriksen@statkraft.com
Husebye, Anja Sidseldatter	Statkraft Development	Anje.Husebye@statkraft.com
Notkevich, Leon Eliassen	Statkraft Development	Leon.EliassenNotkevich@statkraft.com
Bråten, Jan	Statnett SF	
Hauglum, Kjartan	Statnett SF	Kjartan.hauglum@statnett.no
Jenssen, Bjørn Hugo	Statnett SF	Bjorn.jenssen@statnett.no
Kirkeluten, Øystein	Statnett SF	Oystein.kirkeluten@statnett.no
Mork, Rune Kristian	Statnett SF	rune.mork@statnett.no
Skyberg, Berit	Statnett SF	berit.skyberg@statnett.no
Bratland, Sjur E.	StatoilHydro	sjub@Statoilhydro.com
Haglerød, Klaus Kristian	StatoilHydro	kkha@statoilhydro.com
Karlsen, Elly	StatoilHydro	ELKAR@StatoilHydro.com
Nielsen, Finn Gunnar	StatoilHydro	
Skaare, Bjørn	StatoilHydro	bjoska@statoilhydro.com
Norlund, Fredrik	Svenska Kraftnät	Fredrik.Norlund@svk.se
Blomquist, Jens Peter	Sway AS	jpb@sway.no
Borgen, Eystein	Sway	
Holmefjord, Svein	Sway AS	sh@sway.no
Mæland, Kai	Sway AS	km@sway.no
West, Mark	Sway AS	mw@sway.no
Lauvdal, Terje	Sweco Grøner	tlauvdal@online.no
Sandgren, Jonas	Sweco Grøner	Jonas.sandgren@sweco.no
Aase, Perry	Tafjord Kraftproduksjon	perry.aase@tafjord-kraft.no
Hernandez, Claudio	Troll Power AS	claudio.hernandez@trollpower.no
Johansen, Børre	Troll Power AS	Borre.Johansen@TrollPower.no
Haarberg, Per Olav	TRPOH	trpoh@online.no
Lorås, kåre	TrønderEnergi Kraft AS	kl@tronderenergi.no
Nygaard, Tor Anders	UMB	tor.anders.nygard@umb.no
Skomedal, Nere	Umoe Mandal AS	nere.skomedal@um.no
Loman, Göran	Vattenfall	goran.loman@vattenfall.com
Pedersen, Theis H.	Vestas Northern Europe	thpe@vestas.com
Christensen, Peter	Vestas Technology AS	PEWCH@vestas.com
Båtevik, Beate Valaker	Vestavind Kraft	beate.baatevik@vestavindkraft.no
Kjellesvik, Jarle	Vestavind Kraft	Jarle.kjellesvik@haugaland-kraft.no
Kvernevik, Edgar	Vestavind Kraft	Edgar.Kvernevik@vestavindkraft.no
Sandvik, Håkon	Vestavind Kraft	Haakon.sandvik@vestavindkraft.no
Svendgård, Ole	VIVA AS	Ole.svendgard@inergo.no
Hansen, Gunn Spikkeland	VRI Rogaland, Polytec	hansen@polytec.no
Lemström, Bettina	VTT	bettina.lemstrom@vtt.fi
Uski-Joutsenvuo, Sanna	VTT	sanna.uski-joutsenvuo@vtt.fi
Nilsen, Roy	Wärtsilä	Roy.Nilsen@wartsila.com

Energi for fremtiden

Vindkraft – en av klimaløsningene, Guri Størvold OED

Politikk og folkelig aksept av vindkraft, PhD Jøran Solli, NTNU

Vind og vannkraft – en gylden mulighet for norsk kraftbransje, Adm.dir. Lars Audun Fodstad, Sira Kvina Kraftselskap

Offshore vindkraft – FoU aktivitet og foresight 2027, Seniorforsker John Olav Tande, SINTEF Energiforskning

The role of wind power in meeting the EU target of 20 % renewables by 2020 – Tradewind, Technical Consultant Frans van Hulle, EWEA

OLJE- OG ENERGIDEPARTEMENTET

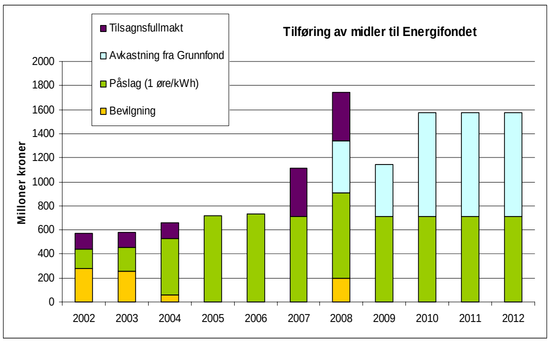
Norsk energi- og miljøpolitikk

Vindkraft – en del av fremtidens løsning

Statssekretær Guri Størvold
Olje- og energidepartementet
24. januar 2008

"Norge skal være en miljøvennlig energinasjon og være verdensledende innenfor utvikling av miljøvennlig energi"

Energiomlegging – Enova og Energifondet



Nye samtaler med Sverige om grønne sertifikater til fornybar elektrisitet

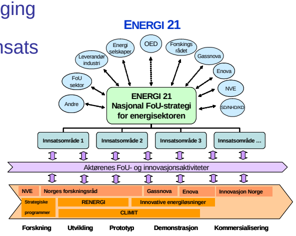
- Utviklingen det siste året har gjort at støtteordningen for fornybar elektrisitet i dag framstår som for dårlig.
- Naturlig å se på nytt på mulighetene for å etablere et felles marked for pliktige sertifikater.

Investeringsstøtte til fornybar elektrisitet

- Fram til sertifikatmarkedet er på plass vil investeringsstøtte til fornybar elektrisitet innenfor dagens notifiserte ordning styrkes.
- Dersom det ikke lykkes å komme frem til et resultat om grønne sertifikater innen 1. juli 2008, vil regjeringen komme tilbake til Stortinget med et forslag til omlegging av ordningen for fornybar elektrisitet.

Økt FoU-engasjement – Energi21

- FoU viktig for energiomlegging
- Men behov for økt FoU-innsats fra næringslivet
- Ny FoU-strategi under utarbeidelse – Energi21
- Mer samordnet og økt engasjement innenfor energisektoren
- Forslag til strategi 5/2-08



Offshore vindkraft – store muligheter?

- Nytt demo-program på 150 mill kroner
- Stort energipotensial langs norskekysten
- Norge lang erfaring i offshorevirksomhet
- Langsiktig perspektiv

Konsesjonsbehandling – veien til de beste prosjektene

- Svært mange prosjekter under behandling i dag
  - 81 meldinger og 41 søknader hos NVE
  - 11 klager hos OED
- Nettkapasitet og hensyn til natur og lokale synspunkter gir klare begrensninger for hva som kan realiseres

Styrket beslutningsgrunnlag for å sikre koordinering og forutsigbarhet

Konsesjonsbehandling er det sentrale verktøyet for avveining av miljø- og brukerinteresser

Styrket beslutningsgrunnlag:
- Regionvis samordning av konsesjonsbehandling
- Retningslinjer og regionale planer

Formål: Styrke grunnlaget for en helhetlig vurdering av konsesjonssøknader og gjøre denne prosessen mer effektiv og forutsigbar
➔få frem de gode prosjektene

Prioritering av vindkraftsøknader

Stort antall meldinger og søknader gjør at NVE må prioritere;
- Prosjekter som kan bidra til å styrke forsyningsikkerheten, særlig i utsatte regioner. Dvs. bl.a. Midt-Norge

Havbasert vindkraft
- energipotensial, teknologi, regulerbar vannkraft
- FoU, demonstrasjon
- rettsgrunnlag, arealavklaring

Vi skal ha en økt satsing på fornybar energi

- **Vindkraft er åpenbart en del av løsningen – både til vanns og til lands!**
  - **Økte midler til Enova**
  - **Økte midler til forskning allerede i år**
  - **Samtaler med Sverige om grønne sertifikater**
  - **Nytt demoprogram for nye teknologier**
- **www.oed.no**

Vindkraft og folkelig aksept

- Nasjonal motstand, lokal støtte

Jøran Solli
Institutt for tverrfaglige kulturstudier
Senter for energi og samfunn

Der borte…og her hjemme

- Litt om noen britiske studier av vindkraftens miljøkonsekvenser og folkelig aksept
- Hva har vi ved Senter for Energi og Samfunn funnet ut om vindkraft og folkelig aksept?

Studier av vindkraft og de som flyr rundt: turister og fugl

- Få entydige resultater
- Konsekvenser for *turisme*. En studie basert på intervju av turister i Wales og Skottland viste både positive og negative holdninger til vindkraft (NFO System Three, 2002, 2003).
- Konsekvenser for *fugleliv*:
  - Rapporter om negative konsekvenser for havørnbestand på f. eks Smøla.

    samtidig

  - Anlegg i Skottland som er lokalisert i et ørneområde og i et trekkrute for gjess har vært operativt i to år. Så langt har det gitt et negativt resultat for to ryper og en tårnfalk (Ross 2006).

Endringer i lokalbefolkningers holdninger Før og etter- studier

- En studie av fire anlegg i Skottland: andel av respondentene som forventet negative konsekvenser var 40%, mens det etter bygging var 9 % som rapporterte om negative konsekvenser (Dudleston, 2000)
- En studie av 10 anlegg i Skottland: andel av respondentene som forventet negative konsekvenser var 48%, mens det etter bygging var 18 % som rapporterte om negative konsekvenser (Braunholz, 2003)

Endringer i lokalbefolkningers holdninger

- Carland Cross wind farm (*D.C Eltham et al. / Energy Policy 36 (2008)*)
- 14 års drift, 6 MW,15 turbiner
- Lokalisert på det høyeste punkt i et lite dyrket myrområde, godt synlig fra det stedet hvor den intervjuede lokalbefolkningen bodde
- Funn:
  - Nærværet av vindparken førte ikke til at lokalbefolkningen fikk negativ holdning til økt utnyttelse av vindenergi i Storbritannia
  - På tross av mange negative medieoppslag i planperioden hadde vindparken relativ stor støtte i lokalbefolkningen
  - Ingen større holdningsendringer i forhold til et sett av negative og positive konsekvenser fra planleggingsperioden i 1991 til 2006

Carland Cross wind farm

- Stor prosentvis økning i andelen av befolkningen som la vekt på det positive bidraget til forsyningssikkerhet. Fra 6% i 1991 til 41 %
- Stor prosentvis økning i andelen av befolkningen som mente vindparken var "visually attractive" fra 6 % til 40 %
- Den største bekymring i 1991 var ikke det visuelle inntrykket, men mulig støy. Kan delvis forklares ved størrelsen på installasjonene.
- Nye positive (og overraskende) momenter i 2006 som ikke var vektlagt i 1991
  - Glede ved reflektering av lys
  - Navigasjonsstøtte

Konklusjoner del I

- Økt betydning av positivt bidrag til forsyningssikkerhet
- NIMBY synes ikke å utgjøre avgjørende del av folkelig motstand, men andre sosiale, kulturelle og institusjonelle faktorer spiller en viktigere rolle
- Men relativt lite forskning på hva skjuler seg blant disse "faktorer"?

Vindkraftstudier ved Senter for Energi og Samfunn

- Studie av avisdekning av vindkraft
- Studie av lokale vindkraftdebatter i Norge
- Studie av vindkraftdebatt i Storbritannia

- For å vite mer om mekanismer rundt det med folkelig aksept, så ser vi på drivere i vindkraftkonfliktene, på hvordan motstanden formes og gjøres virksom

Funn I: Hvorfor er vindkraft miljøpolitisk omstridt?

- Miljøpolitisk skille mellom de som legger vekt på naturvern i klassisk forstand (verne om det uberørte) og de som finner det riktig å prioritere produksjon av fornybar energi.
- To forskjellige forståelser av bærekraftighet, som i konkrete vindkraftkontroverser blir gjort aktive som to ulike strategier eller fortellinger
  - ny, fornybar energiproduksjon
  - vern av natur og naturopplevelser
- Gjenspeiler at naturen kan forstås på flere måter
- Utfordring: Å forene de to forståelsene av bærekraft
  - Lokalisering
  - Landskapstilpasning
  - Biodiversitet

Ulike drama spilles ut

- Konfliktene knyttet til *lokalisering, landskapstilpasning og biodiversitet* er formet gjennom ulike drama
  - Samfunnsdramaet
  - Naturdramaet

Lokaliseringens samfunnsdrama

- Mange kommuner ønsker prosjektene velkommen ved at de kan generere inntekter
- Skaper et utgangspunkt for lokal folkelig støtte
- Motsetningsforhold mellom nasjonal motstand: sentralt plassert forvaltning og organisasjoner (+ hytteeiere) og lokal støtte
- Et samfunnsdrama med likhet til konfliktene rundt vannkraftutbygging på 70-tallet

Naturverntankegangen får gjennomslag – hvorfor?

- Utbredt oppfatning av det finnes alternativer til vindkraft som er mindre belastende, særlig energieffektivisering
- Melankoli i forhold til nye satsninger som burde begeistre? (Næss 2007)
  - Påvirket av den dominerende tankegangen om kostnadseffektiv energiproduksjon (hvem blir entusiastisk av kostnadseffektivitet?)
- Vindkraftindustrien har prioritert kostnadseffektivitet snever forstand og derfor lagt vekt på å få til store installasjoner i områder med spesielt gunstige vindforhold
  - prioritert utbygging på steder som oppfattes som særlig verneverdige.

Naturdramaet slår inn i ulik grad

- Vektlegging av
  - Biodiversitet
  - Naturlandskapet
- Konfliktnivået i naturdramaet er avhengig av *naturobjektet* som dramatiseres

Betydningen av å velge roller i naturdramaet

- Vindkraftmotstanderne synes å kjøre en prøve og feile - prosess for å velge ut de naturobjekter som de tror har størst lokal støtte – og som kan spille en rolle i naturdramaet
  - Havørna og myrsnipa – betydelig forskjell i symbolsk betydning
    - Smøla: Havørna ikke veldig stor støtte lokalt, men større nasjonalt.
    - Høg Jæren: Myrsnipa viste seg unnselig både lokalt og nasjonalt, så naturlandskapet ble etter hvert valgt i den sentrale rollen

Konklusjon del 2 : Kontroverser å lære av?

- Industrien har selv bidratt til at vindkraft er blitt symbolsk omdefinert fra å være miljøvennlig til å bli et potensielt naturvernproblem
- Utbyggerne må i fremtiden interessere seg mer for å lage anlegg som kan tilpasses områder med lavere verneverdi og noe mindre vind
  - teknologiutviklingen vil foregå på litt andre premisser enn de som dominerer i dag.
  - endring i den energipolitiske tenkningen som gir en forholdsvis ensidig prioritering av kostnadseffektivitet framfor miljøhensyn
- Biodiversitet og naturdrama
  - Naturdrama med havørn påvirker den nasjonale opinionen
  - Biodiversitet må inn som designkriterium
- Nasjonale debatter i de fleste tilfeller mer avgjørende enn lokale

Hva vi ikke vet så mye om…

- Ukjent, men trolig betydelig potensial fremover:
  - betydningen av klimatrusselen for befolkningens holdninger til vindkraft

EUs vedtak om fornybare energikilder i Berlin 9.mars 2007

- **En kjempesjanse for Norge**
- **Griper vi den?**

Lars Audun Fodstad, Adm. direktør, Sira-Kvina kraftselskap

Visjon med tre hovelementer

- **Norsk vannkrafts reguleregenskaper**
- **Vindmøller til havs energipotensial**
- **Offshore supergrid**

Bakgrunn – internasjonalt nettverk

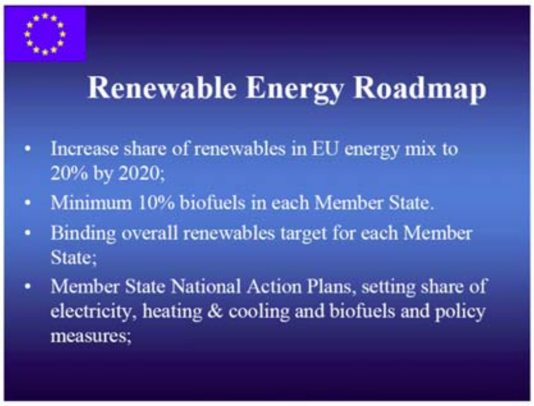
EURELECTRIC – "Europeisk EBL"

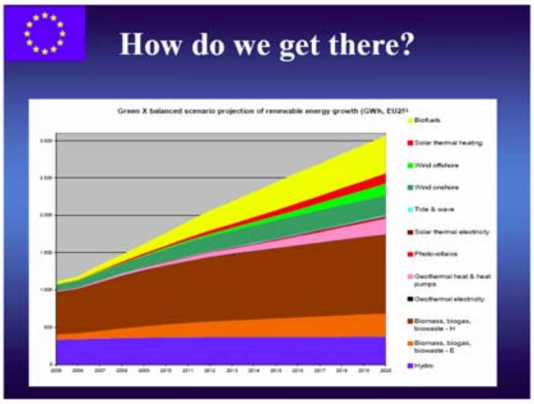
- **WG RES &DG – Arbeidsgruppen for fornybare energikilder og distribuert generering**
  Lars Audun Fodstad norsk medlem siden starten for snart ti år siden

IEA – International Energy Agency under OECD

- **ENARD – Implementing Agreement on Electrical Networks, Analysis, Research and Development**
  Lars Audun Fodstad norsk medlem av Executive Committee

Klipp fra EU-kommisjonens representants foredrag i Bryssel 18.04.07





Hva betyr dette i praksis i 2020?

•34% av alt elektrisitetsforbruk i EU fra fornybare kilder

- Bio
- Vind – fra < 100 TWh i 2006 til ca. 450 TWh i 2020
  - Onshore
  - Offshore

•18% av alt elektrisitetsforbruk i EU fra intermitterende kilder

•Kjempestort behov for kilder med reguleringsevne

- Vannkraft med magasiner er ideell leverandør
- Skal vi doble installasjonen i norske vannkraftverk?

Hvor finnes vannkraft med magasiner i Europa?

Det etterfølgende klipp er hentet fra professor dr. Jürgen Schmid og viser at:

Norge alene har nesten 50 % av magasinkapasiteten i Europa

•Denne kapasiteten kan utnyttes mye bedre til regulering ved installasjon av mer effekt

•Vi behøver ikke flere vassdragsreguleringer med de miljøinngrep de representerer

•Vi trenger bare nye tunneler og større maskinkapasitet

Storage Hydro Power in Europe:
Rated Power, Storage Capacity and Annual Energy Production

Data of UCTE 1998	Rated Power of Reservoir and mixed pumped Storage [GW]	Storage Capacity of Reservoir and mixed pumped Storage [TWh]	Annual Energy Prod. of Reservoir and mixed pumped Storage [TWh]
Slovenia/Croatia	1,4	1,8	?
Switzerland	8,2	8,4	18,0
Serbia and Montenegro	2,0	2,0	?
Portugal	2,1	2,6	4,2
Austria	5,6	3,2	7,0
Luxemburg	0,0	0,0	0,0
Italy	7,5	7,9	17,6
Greece	1,9	2,4	2,8
France	11,6	9,8	18,2
Germany	1,4	0,3	1,1
Belgium	0,0	0,0	0,0
Spain	7,7	18,4	16,7
Sum of UCTE	**49**	**57**	**86**
Data of NORDEL			
Norway	27,3	84,1	112,6
Finland	2,9	4,9	12,6
Sweden	16,2	33,7	63,6
Sum of NORDEL	**46**	**123**	**189**
Sum of NORDEL + UCTE	**96**	**180**	**275**

Offshore supergrid?

- Formål
  - Transport av offshore vindproduksjon til lands
  - Knytte sammen ressurser over større område
  - Muliggjøre bruk av norsk vannkrafts reguleringsevne
- Klipp følger fra
  - Prof. Dr. - Jürgen Schmid, Tyskland
  - The Economist June 28th 2007
  - Airtricity, Irland

Norwegian Hydro Power as an Ancillary for Europe - are the needs larger than earlier?

Prof. Dr. Jürgen Schmid

Member of WBGU - „Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen "

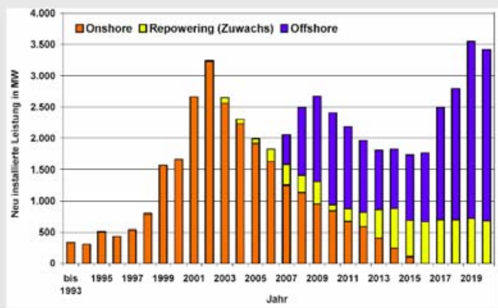
Chairman of the Executive Board of „Institut für Solare Energieversorgungstechnik - Verein an der Universität Kassel e. V."

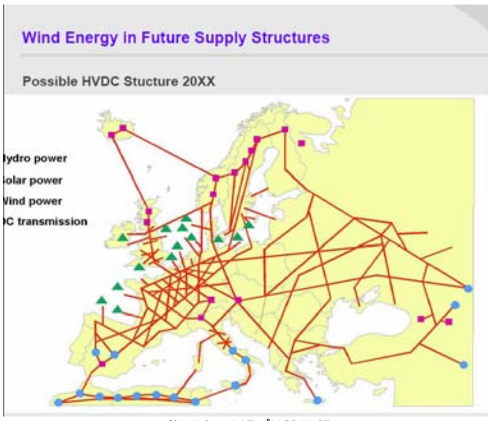
Coordinator of the European Research Cluster on Smart Grids "IRED"

Speaker of the German Section of the European Academy of Wind Energy EAWE

- Wind energy development
- Expansion of wind energy
- Offshore wind energy
- Change of energy supply structures
- dena grid study
- "New sources" of renewable energies
- Wind energy in future supply structure
- European research on future supply structures
- Outlook

Wind Energy Development





Sira-Kvina - LAF - ÅH 09.11.07

The Economist 20070628 side 73:

Wind power has two problems. You don't always get it where you want it and you don't always get it when you want it.

According to Jürgen Schmid, the head of ISET, an alternative-energy institute at the University of Kassel, in Germany, continent-wide power distribution systems in a place like Europe would deal with both of these points.

The question of where the wind is blowing would no longer matter because it is almost always blowing somewhere. If it were windy in Spain but not in Ireland, current would flow in one direction. On a blustery day in the Emerald Isle it would flow in the other.

Sira-Kvina - LAF - ÅH 09.11.07

The Economist 20070628 side 73 forts.:

Dealing with when the wind blows is a subtler issue.

In this context, an important part of Dr Schmid's continental grid is the branch to Norway. It is not that Norway is a huge consumer. Rather, the country is well supplied with hydroelectric plants. These are one of the few ways (but not the only way, see article) that energy from transient sources like the wind can be stored in grid-filling quantities. The power is used to pump water up into the reservoirs that feed the hydroelectric turbines. That way it is on tap when needed.

Sira-Kvina - LAF - ÅH 09.11.07

The Economist 20070628 side 73 forts.:

The capacity of Norway's reservoirs is so large, according to Dr Schmid, that should the wind drop all over Europe—which does happen on rare occasions—the hydro plants could spring into action and fill in the gap for up to four weeks.

Put like this, a Europe-wide grid seems an obvious idea.

Sira-Kvina - LAF - ÅH 09.11.07


Supergrid

Republic of Ireland
Airtricity House
Ravenscourt Office Park
Sandyford
Dublin 18
Ireland
Tel: +353 (0)1 213 0400
Fax: +353 (0)1 213 0444
Email: info@airtricity.com

Northern Ireland
Airtricity Energy Supply Northern Ireland
83–85 Great Victoria Street
Belfast
BT2 7AF
Northern Ireland
Tel: +44 (0)28 9043 7470
Fax: +44 (0)28 9043 7750
Email: info-belfast@airtricity.com

Airtricity Developments Northern Ireland
6A Dublin Road
Omagh
Co. Tyrone
BT78 1ES
Northern Ireland
Tel: +44 (0)28 8225 1031
Fax: +44 (0)28 8224 5213
Email: info@airtricity.com

Scotland
29A Union Street
Greenock
PA16 8DD
Scotland
Tel: +44 (0)1475 892 344
Fax: +44 (0)1475 722 889
Email: scotland-info@airtricity.com

England and Wales
Airtricity
Unit 1, Dyfi Eco Parc
Machynlleth, Powys
SY20 8AX
Wales
Tel: +44 (0)1654 705 000
Fax: +44 (0)1654 703 000
Email: england-walesinfo@airtricity.com

USA
Headquarters, Airtricity Inc.
401 North Michigan Avenue
Suite 3020
Chicago
IL 60611
USA
Tel: +1 312 923 WIND (9463)
Fax: +1 312 923 9469
Email: US-info@airtricity.com

Airtricity

www.airtricity.com

Sira-Kvina - LAF - ÅH 09.11.07

The European Offshore Supergrid

Sira-Kvina - LAF - ÅH 09.11.07

3.5 Introducing the European Offshore Supergrid

- *The Supergrid is a high voltage sub sea transmission network.*
- *It could ultimately cover the Baltic Sea, North Sea, Irish Sea, English Channel, the Bay of Biscay and the Mediterranean.*
- *The Supergrid treats wind as a continental resource and enables EU member states to share in this enormous energy source, to their mutual advantage.*
- *This will be achieved by the member states cooperating in the capture of their common wind resources and the conversion of this free energy into a reliable and predictable supply of electricity.*
- *As power is always being generated on the Supergrid it can be fed into the national grids to meet electricity demand.*
- *The Supergrid also acts as an interconnector between national markets and thereby helps to create a properly functioning internal market in electricity.*
- *This will bring additional benefits for European consumers in terms of greater competition, lower prices and increased security of supply.*

'ABB – Power and productivity for a better world

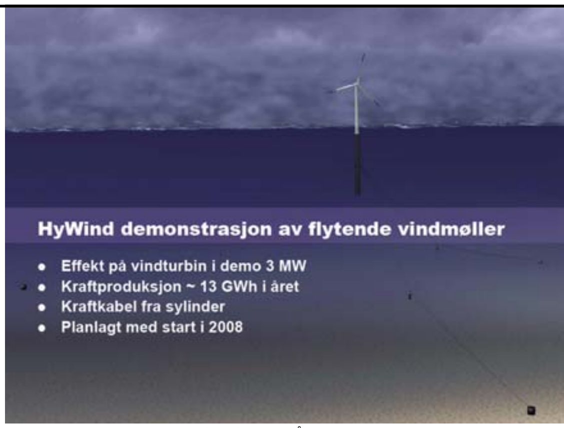
We have today established an advanced transmission technology, HVDC Light, for demanding offshore applications to feed electricity to platforms but also to connect and support integration of electrical networks. We have worked very closely with Airtricity on the technology aspects of their concept for an EU Supergrid Project and have concluded that this European technology fits well with their plans to construct an offshore grid.'

Bo Normark, Senior Vice President Marketing and Sales, ABB Grid Systems

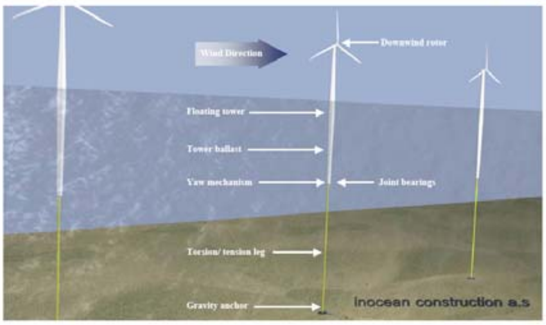
European Offshore Supergrid Proposal

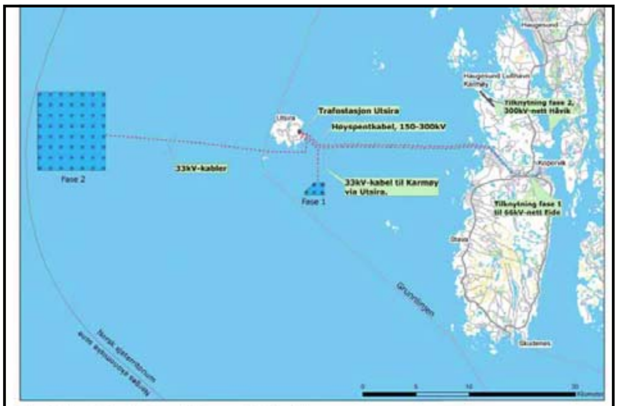
Vindmøller til havs

- **Klipp følger fra to store norske prosjekt med flytende møller for dypt vann**
  - **HYWIND, Hydros etter hvert Statoils**
  - **SWAY, og Lyses melding til NVE**
- **Samt ett stort norsk/internasjonalt prosjekt for grunnere vann**
  - **OWEC Tower AS**



SWAY flytende vindmølle





Figur 2. Alternativ 1; trafostasjon på Utsira og nettilknytning på Karmøy.

3.3 *Vindparken til havs*

Utsira offshore vindpark planlegges bygd ut trinnvis, for gradvis å teste ut ny teknologi og etablere en kostnadseffektiv norsk industri for bygging av flytende vindkraftverk.

Planen er å installere rundt 60 vindturbiner med 5 MW effekt per enhet. Det kan også bli aktuelt å installere turbiner med større effekt. Avstanden mellom hver vindturbin i havparken vil være ca 1 km. Endelig turbinplassering vil bli vurdert nærmere i detaljplanleggingen av prosjektet.

Sira-Kvina - LAF - ÅH 09.11.07

I første omgang (fase 1) planlegges utbygging av inntil fem vindturbiner på ca 150 meters havdyp sørøst for Utsira. Fase 1 planlegges innenfor et areal på ca 2 km^2. Avstanden fra Utsira til den nærmeste turbinen vil være ca 4 km. Fase 1 vil ha en installert effekt på ca 25 MW, og kraften vil mates inn på det regionale kraftnettet på Karmøy.

I senere byggefaser planlegges resterende del av vindparken utbygd på ca 270 meters havdyp vest for Utsira. Fase 2 planlegges innenfor et område på ca 47 km^2. Avstanden fra Utsira til den nærmeste turbinen i fase 2 vil være ca 17 km. Totalt vil vindparken bestå av en installert effekt på ca 300 MW, med en forventet kraftproduksjon på mer enn 1,2 TWh per år.

Sira-Kvina - LAF - ÅH 09.11.07

A tower/foundation for offshore wind farms
OWEC Jacket Quattropod
The Design and Application on Beatrice and elsewhere

OWEC Tower AS

Sira-Kvina - LAF - ÅH 09.11.07

OWEC Jacket Quattropod - UNIQUE Features

- 40-50% of weight (hence cost) can be saved compared to current "State-of-the-Art" design
- Increasing water depth with a minimum of extra steel
- Offshore water depths of more than 50 m can be made economically feasible
- OWEC Tower will – through local licensees – offer locally manufactured substructures
- Technology protected by pending patent
- Comprehensive and unique experience through the DOWNVInD project and studies for Developers/Utilities

OWEC Tower AS

Sira-Kvina - LAF - ÅH 09.11.07

The Beatrice demonstrator project

- Managed by Talisman Energy in Scotland supported by Scottish and Southern Energy
- Supported by EU's 6th Framework Program and British authorities
- Total budget including scientific program: 40 mill €
- OWEC Jacket Quattropod was selected after screening and comprehensive studies on various concepts
- Two full scale demonstrators will be installed July 2006

OWEC Tower AS

Sira-Kvina - LAF - ÅH 09.11.07

Potensial i Norge

- Teknisk – økonomisk mulig å konkurrere med vindkraft på land og gasskraft?
- Hvis ja har Norge en gigantisk uutømmelig fornybar energikilde til "evig tid"
- De 6 svarte firkantene representerer totalt et areal på 1 promille av norsk økonomisk sone og ville kunne produsere 30% av vannkraftproduksjonen.
- Må tilpasses eksisterende virksomheter som fiskeri og skipstrafikk

Sira-Kvina - LAF - ÅH 09.11.07

Kombinasjon av:

- •Effekt i norske vannkraftverk
- •Supergrid i Nordsjøen
- •Havmøller

Kan bidra til:

- •EU når sine mål om fornybare
- •Ny æra for norsk vannkraft
- •Elektrifisering av sokkelen fra fornybare kilder
- •Betydelig norsk industriell offshore spinoff

Tar vi utfordringen, eller lar vi den gå forbi?

Vi trenger:

- •Nasjonal bevisstgjøring og satsing
- •Internasjonalt samarbeid
  - ➢ EU - Nordsjølandene
- •Lovregulering og myndighetsorgan for aktiviteten
  - ➢ bruken av havområdene til elektrisitetsproduksjon og overføring
  - ➢Hjemmel for overordnet styring
  - ➢"NVE"/"Statnett" for havområdene
  - ➢Ny internasjonal havrett? – ny Evensen-runde?
- •Støtte for å sikre god fremdrift for de nødvendige teknologiprosjektene

Vi trenger også:

- •Mulighetsstudier / kartlegging
  - ➢Hvor kan effektinstallasjonen i vannkraftverkene økes, til hvilke kostnader og med hvilke konsekvenser
  - ➢Hvordan kan effektinstallasjonene best tilknyttes et supergrid i havet
  - ➢Hvor bør offshore vindparker fortrinnsvis lokaliseres med hensyn til fiskeri, navigasjon, olje- og gassaktivitet og miljøspørsmål
  - ➢Hvordan kan et supergrid etableres og tilknyttes det øvrige europeiske systemet
- •Overordnet koordinering av arbeidet
  - ➢Koordineringsgruppe, liten og effektiv med klart mandat
  - ➢Referansegruppe hvor alle aktuelle parter kan bidra

Fremdrift

- •EU-systemet arbeider under et sterkt tidspress og de vil finne løsninger
- •Fremdriften i arbeidet fra norsk side er avgjørende for å ivareta norske muligheter og interesser
- •Det må arbeides parallelt på en rekke områder, en seriell arbeidsmåte blir for langsom
- •Arbeidet bør igangsettes umiddelbart og prioriteres høyt
- •Koordineringsgruppen må tilføres nødvendige ressurser

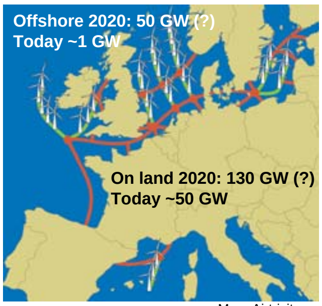
Innspill og eventuelle korreksjoner mottas med takk!

Lars Audun Fodstad
Adm. direktør
Sira-Kvina kraftselskap
p.b. 38
N-4441 Tonstad
Tel.: +47 38 37 81 15
Faks: +47 38 37 80 01
Mob.: +47 913 01 785
e-post: laf@sirakvina.no

Offshore vindkraft – FoU aktivitet og foresight 2027

John Olav Giæver Tande
SINTEF Energiforskning AS
john.o.tande@sintef.no

EU target 2020: 20 % renewable energy



Map: Airtricity

180 GW wind ~ 530 TWh/y ~ 15 % of EU el load

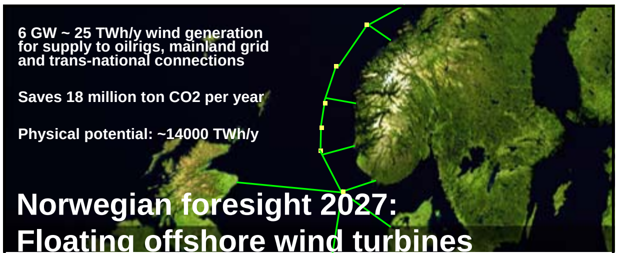
An offshore "SuperGrid" may provide for connection of offshore wind farms and efficient trans-national exchange of power

Norway can contribute with hydro for balancing, but also take active part in an offshore wind development

Norwegian wind energy potential

- Very good wind conditions both on land (~3000 h/y) and offshore (4-5000 h/y)
- Tremendous physical potential[1]
  - on land +1000 TWh/year
  - offshore (0-30 m) 125 TWh/y
  - offshore (30-60 m) 871 TWh/y
  - offshore (60-300 m) 12970 TWh/y
  - annual el consumption in Norway ~120 TWh
  - oil and gas export 2500 TWh/y (heat value)
- Development is ongoing, but financial support for wind generation is low (0.08 NOK/kWh) and probably not sufficient for many projects
- Developers and industry are still active expecting improved market conditions
- About 1 TWh/y is in operation (all on land)
- Projects totaling +20 TWh/y is in planning

[1]Refs: NVE and Enova

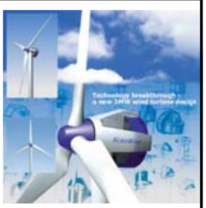


Norwegian foresight 2027: Floating offshore wind turbines

- **Tremendous physical potential**
  0-30 m: 125 TWh/y; 30-60 m: 871 TWh/y; 60-300 m: 12970 TWh/y
  (Norwegian hydro 125 TWh/y; oil and gas export 2500 TWh/y)
- **Norwegian industry and energy companies are active combining offshore and energy expertise to develop sound technology**
- **Global market – a unique possibility for developing new industry**
- **SINTEF, IFE and NTNU is heading R&D with key actors as participants**

Norwegian research focus: Deep sea wind turbines

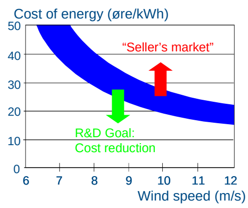
- **Installation at deep sea far from shore:**
  - Unlimited potential and high energy output
  - Minimized negative environmental impact
  - Cost competitive renewable generation
- **Challenges:**
  - Bigger, lightweight and strong wind turbines (10 MW, 160 m wingspan ~ twice a jumbo jet)
  - Foundation / floater (design, installation, O&M)
  - Grid connection (AC, HVDC, multi-terminal)
  - Power system integration of large scale wind (mainland and offshore oilrigs)
- **Key Norwegian industry stake-holders:**
  - ScanWind; large wind turbines
  - StatoilHydro and Sway; floater concept
  - Owec Tower; jacket structure
  - Aker Kværner, Nexans, Devold AMT, Umoe etc; sub-supplies of components & services
  - Statkraft; Lyse etc; wind farm developers
  - Statnett; transmission system operator



SINTEF, IFE and NTNU cooperate in wind energy R&D

- Cooperation gives complementary know-how and strength.
- Extensive lab facilities: Test station, wind tunnel, ocean basin, electro-technical lab, materials fatigue testing ++
- Internationally well acknowledged
- Member of European Academy of Wind Energy (www.eawe.eu)
- Strength areas are offshore technology and grid integration
- Strategic goal is to increase wind R&D activity through new large national projects, EU-projects and international networks

www.sffe.no www.sintef.no/wind



Example projects and activities

Previous:

- ”Development of Norwegian wind power technology” (2001-2005) Funding: Norwegian Research Council, Statkraft, Umoe and Hydro. Total budget ~12 mill NOK including 2 PhD.
- ”Strategic wind power programme” (2003-2007) Funding: Norwegian Research Council. Total budget ~20 mill NOK including 7 PhD and 1 Post Doc.

Ongoing:

- “Deep sea offshore wind turbine technology” (2007-2009) Funding: Norwegian Research Council, StatoilHydro, Statkraft, Lyse, Statnett, Umoe and Nexans. Total budget 18 mill NOK including 3 Phd
- “Offshore Renewable Energy - SFFE PhD pool” + Statkraft & NTNU agreement; SUM +10 Phd
- Well acknowledged and active internationally (EU projects, IEA, IEC)
- Extensive lab facilities: Test station, ocean basin, wind tunnel, material fatigue testing and electric machinery & power electronics lab

Next step:

- Establish wind R&D in Centre for Research Based Innovation (SFI)

NFR KMB Deep sea offshore wind turbine technology

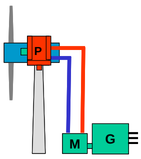
2007-2009 / total budget 18 mill NOK

- **The project combines wind technology know-how with offshore and energy industry experience to enhance development of deep sea wind farms.**
- **The main objective is to advance Norwegian development and pin-point technical solutions aiming for cost-efficiency of deep sea wind farms.**
- **Partners: SINTEF Energy Research, MARINTEK, IFE, NTNU, StatoilHydro, Statkraft, Lyse, Statnett, Umoe, Nexans**

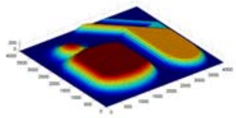
- Task 1: Progress of design tools (analytics, numerical methods and experiments) for the (structural, control, concurrent engineering) design of offshore wind energy concepts. The task includes institute research headed by SINTEF Marintek and one PhD.
- Task 2: Assessment of wind turbine design solutions adapted for deep-sea conditions, including investigation of operational and extreme behaviour. The task includes institute research headed by IFE and one PhD.
- Task 3: Provide solutions for cost effective grid connection and system integration of large deep sea offshore wind farms. The task includes institute research headed by SINTEF Energy Research and one PhD.

VIVA AS
TEST STATION FOR WIND TURBINES

- Lab for wind energy R&D, test, demonstration and documentation
- Example project: ChapDrive – a solution for reduction of top weight



Wind tunnel (NTNU)

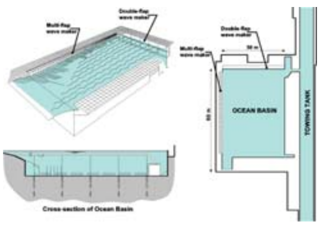


- Example project: A wind tunnel study of flow over a generic complex terrain model (PhD study)

- Wind speed up to 30 m/s
- Test section: 11 x 3 x 2 meters (L/W/H)
- 6-component balance for measurements of the 3 forces and 3 moments
- Equipment for measuring Temperature, Pressure and Velocity (HWA, LDA, PIV)

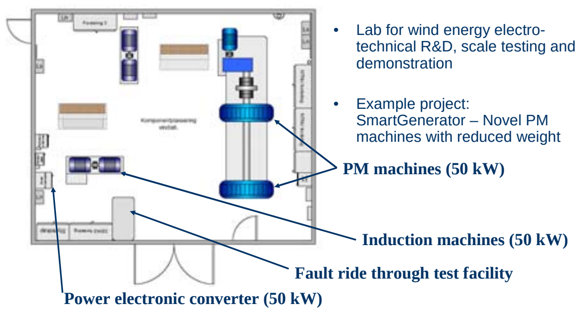
Ocean basin laboratory
(SINTEF Marintek and NTNU)

Example project: Test of HyWind concept in scale 1:46



Wind power electro-technical laboratory
(SINTEF Energy Research and NTNU)

- Lab for wind energy electro-technical R&D, scale testing and demonstration
- Example project: SmartGenerator – Novel PM machines with reduced weight



Material **fatigue** testing (SINTEF/NTNU)

Example project: Test and development of blade materials (PhD study)

25 TWh offshore vind i 2027
Hvordan kommer vi dit – FoU utfordringer:

- Kartlegging av offshore vind og bølgeforhold:
  målemetodikk, vindstruktur, turbulens, simulering/on-line prediksjon.
- Utvikling av numeriske programmer for design av offshore vindturbiner.
- Studie av vindturbin designkonsept:
  antall blader, turtall, oppvinds/nedvinds, gir/generator, tårn, flyter, forankring.
- Studie av parkdesign (størrelse på park, avstand mellom turbiner, vindforhold)
- Utvikling av konsept for internt nett i vindpark og effektiv tilkobling/transmisjon til stamnett og/eller olje og gassplattformer (topologi, AC, HVDC eller miks).
- Teknologiutvikling (kostnadseffektiv, driftsikker og "vedlikeholdsfri" vindturbin):
  - Bladdesign tilpasset drift offshore ("smartblades").
  - Generatorer/kraftoverføring for redusert toppvekt (SmartGenerator og ChapDrive).
  - Tårn og flyter tilpasset forskjellige størrelser på turbin og havdyp.
  - System for elektrisk tilkobling (dynamisk kabel, skjøte og koblingsløsninger, mv).
  - Overvåknings- og kontrollsystem av turbiner og vindpark.
  - Løsninger for frakt (taubåt), forankring og installasjon.
  - Fartøy for inspeksjon og vedlikehold av vindturbinene.
- Strategier for drift og vedlikehold (plan, tilstandsbasert, risikobasert)
- Systemstudie av innpassing av stor andel offshore vind i kraftsystemet, herunder kontrollsystem/driftstrategi som maksimerer systemnytten.
- Studier av samfunnsnytte (energi, industri) og miljøeffekter.

25 TWh offshore vind i 2027
Hvordan kommer vi dit – forslag til tiltak:

- ***Etablering av offshore systemansvar og embetsverk (energilov mv)***
- ***Utarbeide energiplan for norsk sokkel***
- ***Senter for forskning på offshore vindkraft:***
  Konsentrert innsats på området slik at norskutviklet teknologi kan bli ledende på området. Senteret samler de aktuelle forskningsmiljøene (SINTEF, IFE, NTNU) og har deltagelse fra næringslivet.
- ***Nasjonalt test og pilotanlegg:***
  En offshore nettstasjon for tilkobling av et antall offshore generatorer. Anlegget omfatter også måleutstyr, fiber for kommunikasjon, adgang med båt/helikopter, lagerplass og oppholdsrom.
- ***Demonstrasjonsprogram for offshore vindkraft:***
  Program for støtte av test/pilot anlegg gir risikoavlastning for aktørene og sikrer gjennomføring. Støtteordningen omfatter også demoparker.
- ***Styrke norsk industri som leverandører til offshore vind industri:***
  Teknologiutviklingsavtaler og støtte til nyetableringer bidrar til at norsk industri kan utnytte eksiterende fortrinn og være ledende på området.
- ***Attraktive rammevilkår for vindkraft på land og til havs:***
  En strategi for utvikling av vindturbiner til havs må også omfatte utbygging av vindkraft på land. Dette for å sikre kompetanse i alle ledd både når det gjelder bygging og drift av vindkraftverk.

Klimaforliket – et viktig steg

4.5. Demonstrasjonsprogram og strategi for fornybare energiteknologier offshore

- ***[..] et demonstrasjonsprogram for utvikling og introduksjon av nye fornybare energiteknologier offshore med en ramme på 150 millioner kroner i statsbudsjettet for 2009. [..] en nasjonal strategi for kraftproduksjon fra havmøller og andre marine fornybare energikilder. En slik strategi må se på behovet for særskilt forskningsinnsats, vurdere å opprette et eget senter for forskingsdrevet innovasjon på området, utrede nødvendige lovendringer for å kunne utstede konsesjoner, se utplassering av havmøller i sammenheng med elektrifisering av aktivitet på sokkelen og gjennomføre en arealvurdering for utplassering av fremtidige anlegg hvor hensynet til fiskeriene, det marine miljøet og andre næringer ivaretas.***

4.6 Forskning på ny fornybar energi

- ***Partene er enige om at satsingen på forskning og utvikling innen fornybare energikilder og karbonfangst- og lagring må økes, først med 70 mill. kr i RNB 2008 og videre til en total økning på 300 mill. kr i statsbudsjettet for 2009, og til minimum 600 mill kr i [..] 2010.***

Oppsummering & konklusjon

- Kraftig satsning på vindkraft i Europa for å nå 20 % fornybar mål
- Mye vindkraft i Europa gir økt verdi av norsk vannkraft (balansekraft)
- Offshore vindkraft er relativt nytt og i en FoU og demonstrasjonsfase
- Erfarte tekniske problemer med offshore vindkraft kan løses gjennom bruk av marin kompetanse – her kan Norge bidra med mye!
- Prototyper av "flyterkonseptene" HyWind og SWAY vil installeres i løpet av de neste par årene
- Ingen tekniske "show-stoppers" – flytende prototyper kan bygges nå
- Stadig en lang vei å gå i forhold til å finne optimale løsninger og basis for utbygging av store parker på dypt vann
- Behov for bred FoU satsning for å få ned kostnad og risiko for investor

- SINTEF, IFE og NTNU i posisjon til å danne SFI på offshore vindkraft
- En satsning på offshore vindkraft representerer en gylden mulighet for norsk industri – Norge er i tet på utvikling av flyterkonseptet
- Klimautfordringen kan kun løses ved global innsats – Norge kan bidra vesentlig ved å utvikle og demonstrere klimavennlig teknologi

EWEA

Role of wind power in meeting EU target: 20% renewables by 2020

Vindkraft FoU seminar – fremtiden er offshore
Trondheim, 24-25 January 2008

Frans Van Hulle

EWEA

What is the European Wind Energy Association?

EWEA

EWEA members include the following leading companies:

Airtricity, acciona, DONG energy, GE Energy, IBERDROLA, LM Glasfiber, RES, Shell WindEnergy, SIEMENS, Suzlon, VATTENFALL, Vestas

---

EWEA

Outline

- The 2020 renewables target
- EU policy framework
- Wind power capacity growth in view of the target
- Integration challenges
- Conclusions and outlook

EWEA

The twenties target for EU-27

Proposed by the Council in March 2007

More detailed Commission proposal 22 January 08

- 20% improved energy efficiency
- 20% reduction of greenhouse gas emissions (30% if other countries commit)
- 20% binding target for renewable energy
  - Including 10% biofuels

EWEA

European Commission proposal launched yesterday

Proposal for a

DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

on the promotion of the use of energy from renewable sources

Text with EEA relevance

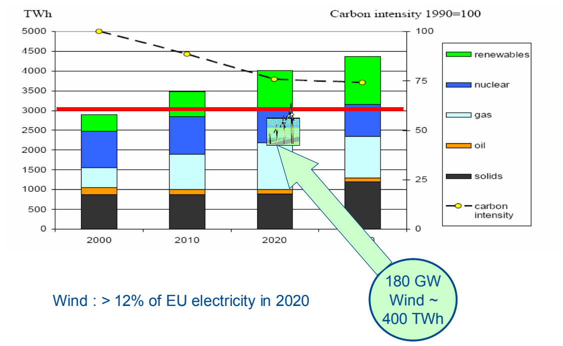
EWEA

20% target: How much renewable electricity and wind power?

- 35% renewable **electricity** is needed to reach the 20% target for renewable energy
- Today RE produces 15% electricity (10% large hydro, 3% wind + ...)
- Excluding large hydro the share of renewable electricity must increase from 5% to approximately 25%
- **WIND POWER**: From 3% (55 GW) today to 12% (180 GW) in 2020 (exact figures depending on 2020 demand)

EWEA

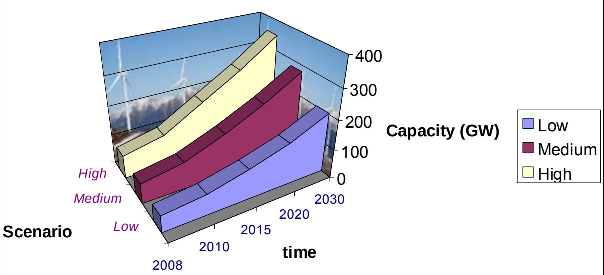
Wind energy more than half of the renewable electricity in 2020



Wind : > 12% of EU electricity in 2020

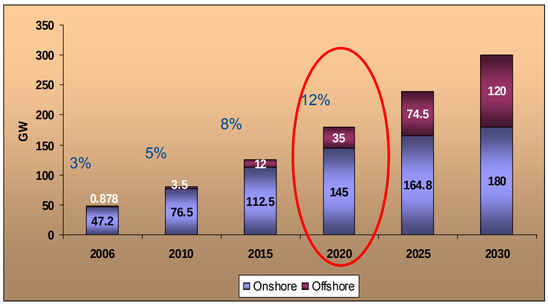
EWEA

Estimated installed WP capacities (TradeWind)



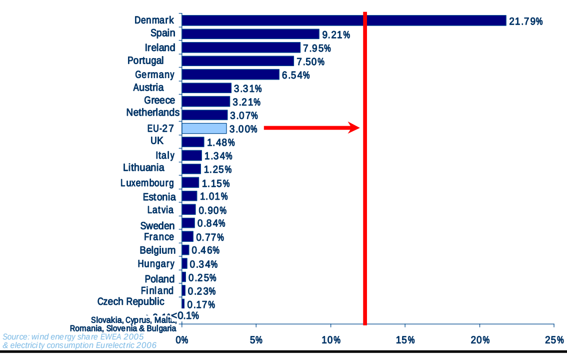
EWEA

Onshore and offshore wind power capacity targets



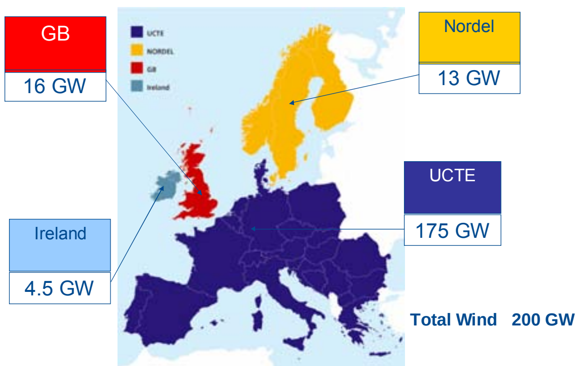
EWEA

Country-wise wind energy penetrations



EWEA

wind power capacity in synchronous zones (2020)



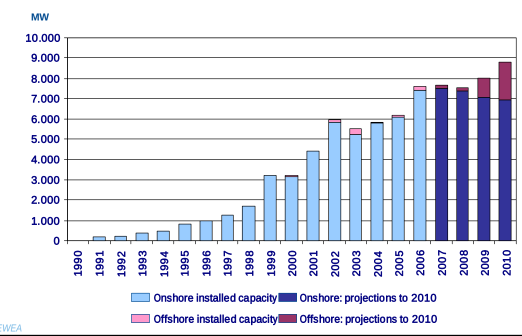
EU Policy Framework

- Internal Electricity Market (2008)
  - Further liberalisation, unbundling
  - TSO cooperation (ENTSO)
  - regulators cooperation (ACER)
- Renewable Energy Directive (2009)
- Priority interconnection plan, TEN-E Revision (2008), European Coordinators (2008)
- Support mechanisms, ETS
- Strategic Energy Technology Plan (SET Plan)
- Offshore Action Plan (2008)

Wind power growth in view of the target

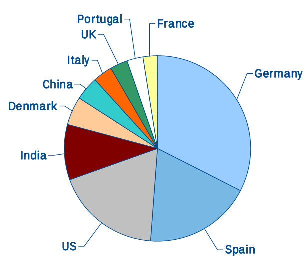
- Average capacity addition needed in next 13 years: 10 GW per year (including 3 GW offshore)
- Because of wind powers capacity factor (average 22%), this will result in quite high wind power capacity penetrations in some member states

Annual European installations keep on growing



Source: EWEA

Top 10 cumulative installed capacity worldwide (2006 - 2007)



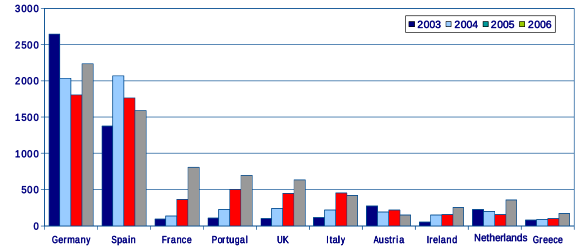
Current 90 GW

Total capacity	MW	%
Germany (1)	20,622	27.8 %
Spain (3)	11,615	15.6 %
US (2)	11,603	15.6 %
India (4)	6,270	8.4 %
Denmark (6)	3,136	4.2 %
China (5)	2,604	3.5 %
Italy (8)	2,123	2.9 %
UK (9)	1,963	2.6 %
Portugal (10)	1,716	2.3 %
France (7)	1,567	2.1 %
Top 10 –Total	63,217	85.2%
Rest of the world	11,004	14.8%
World total	74,221	

Source: EWEA, GWEC

EWEA

Continuous growth in top-10 markets EU-25 (2003-2006)



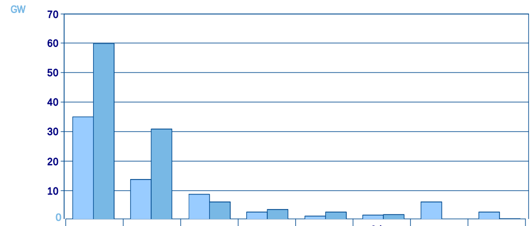
Average Annual Growth Rates

	1995-2000	31.7%
	2000-2005	14.0%

Source: EWEA, GWEC

EWEA

Generation investments: wind in EU second after gas (GW)

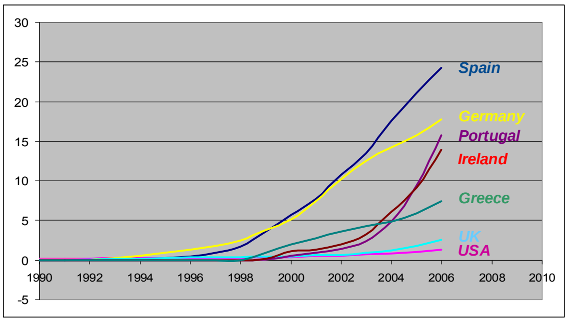


	Natural gas	Wind	Coal	Fuel oil	Large hydro	Other renewables	Nuclear	Others
1997-2001	35.0	13.8	8.7	2.6	1.3	1.6	6.1	2.7
2002-2006	59.9	30.9	6.2	3.5	2.6	1.8	0.3	0.5

Source: Platts, EWEA

EWEA

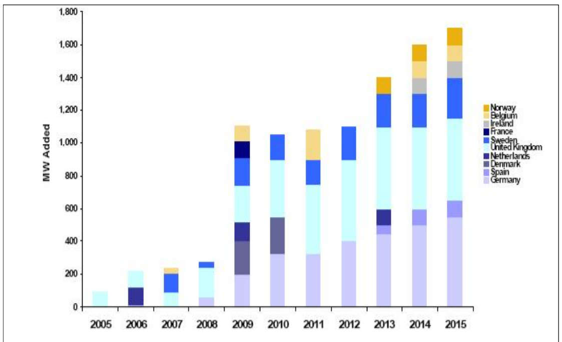
Significant growth of capacity penetration of wind



Andrew Garrad 2007

EWEA

Offshore wind capacity about to take off



Source: Emerging Energy Research

EWEA

Challenges for meeting these wind power targets

- Grid integration aspects (will be further detailed)
- Technology development
  - Strategic Research Agenda,
  - Wind Energy Technology Platform > FP7
- Further market development, onshore and offshore project development // planning and administrative issues
- Industrial policies, in a global context
- Appropriate policy and regulatory framework

European Wind Energy Technology Platform

Specific properties of wind power on the grid

- Variable output technology with its specific predictability characteristics
- Resource all over Europe but not necessarily close to present network (eg offshore)
- (Despite wind dependency), wind power has power plant capabilities. Wind can deliver energy and ancillary services.
- In the system, wind power is mainly a source of energy, but aggregated wind power provides capacity value.
- Wind power capacity can be added fast.
- Wind power (onshore) is to be classified among the cheaper generation sources and has predictable cost

Pillars for large scale integration of wind power

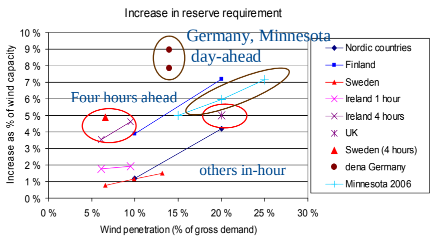
- **Power system design and operation:** to deal with uncertainty and variability needs to be more flexible. Use of wind power prediction tools. Priority access and dispatch for renewables
- **Grid upgrade and interconnection:** extend the European grid to provide transmission capacity, reach the offshore potential, to increase capacity and to better interconnect the balancing areas in Europe
- **Market rules and organisation**: balancing areas in view of aggregated wind power, creation of markets closer to delivery hour (intraday)
- **Connection requirements:** Efficient, economic and fair rules for connection and operation of wind power plants on the grids.

- Enabling **political, legislative and regulatory framework**
- **Supporting Research and Development**

Power system design and operation recommendations

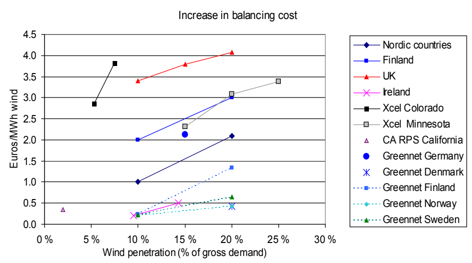
- IEA Task 25 Design and operation of power systems with large amounts of wind power.
- This international platform is working out recommendations based on national and supranational system studies.

Additional balancing requirements



- different time scales for estimating the reserve requirement
- different methodology used

Additional balancing costs



Not directly comparable due to: different time scales; allocating investment for new reserve or only use of reserves; possibilities for power exchange to neighbouring countries; method for calculating costs based on assumptions on thermal power

Examples: Identification of necessary grid upgrades,

- TEN-E Programme: priority axes and projects (2008 revision, co-ordinators)
- National studies: Dena, Denmark, UK, France, NL, Spain
- European wind integration studies, where grid upgrades are identified based on power flow studies
  - TradeWind (interconnection, up to 2030)
  - EWIS (detailed grid study, up to 2015)
- Commercial initiatives such as Offshore SuperGrid, pilot phase of 10 GW

Developments at EU level:
- **ENTSO**
- **ACER**
- **TEN-E**

EWEA

Grid connection requirements: the challenge

- Manufacturers will almost always prefer relaxed grid codes.
- On the other hand grid codes needs to be so strict in due time that a given future penetration level is not blocked due to technical reasons.
- EWEA Working Group is developing industry strategy on European harmonisation (structural / technical) of Grid code requirements for wind power

TradeWind EWEA's integration study

SINTEF, VTT, Garrad Hassan, Risø, KEMA, Tractebel Engineering Suez, dena, Intelligent Energy Europe

WHAT?

- EU wind industry initiative coordinated by EWEA
- 2 years study started November 2006, sponsored by IEEA
- High penetration (23%), large scale integration 300 GW
- EU-27 wide: UCTE + Nordel + GB + Ireland
- Long-term vision spanning 2006-2030

OBJECTIVE

Focus on how to facilitate wind power integration by studying:

- Improved cross border exchange (lines / allocation methods)
- Improved market mechanisms (rules and organisation)

EWEA

TradeWind status

SINTEF, VTT, Garrad Hassan, Risø, KEMA, Tractebel Engineering Suez, dena, Intelligent Energy Europe

DONE SO FAR

- EU wide dispersed WP capacity installed up to 2030 and regionally aggregated wind power production time series
- EU wide survey and analysis of power market mechanisms and how wind power is integrated in market
- EU grid model and simulation tool for calculating the effect of wind on cross-border flows and effects of market rules
- List of significant interconnectors for wind energy

TARGET AND COOPERATION

TEN-E, market parties (regulators, producers, TSO's, power traders), EU and national governments (e.g. TEN-E)

- co-operation and exchange with EWIS study

Further info: session this afternoon

EWEA

Conclusions

- The 2020 targets for RE include 12% wind and will require average additions of 10 GW per year
- Extrapolating present growth this seems reasonable however will require serious boost offshore
- EC is proactively supporting the promotion of RE –new Directive proposed yesterday
- Multiple challenges for wind, but certainly in the field of grid integration
- Several examples of work in areas : power system, grid upgrade, grid codes, markets
- More details about interconnection and markets this afternoon in the TradeWind session

EWEA

Conclusions

- In the coming 25 years substantial additional wind power capacity is expected to make part of the European power system, reaching 300 GW in 2030, energy penetration of 25%.
- Developing such power system involves design and operation (balancing, forecasting, market organisation), grid infrastructure (investments and planning) and WP connection and operation practices and rules
- The process should be supported by R&D into integration issues from European view
- Policies and regulatory mechanisms should focus to an improved functioning of the market and take away risks for investors to enable a cost-effective integration

EWEA

THANK YOU

Vindkraft i Norge

ScanWind status- og veien videre, Markedsdirektør Leiv Låte, ScanWind

Offshore vindkraft og elektrifisering av olje og gass installasjoner,
Marius Holm, Nestleder i Bellona

Statkrafts satsing på offshore vindkraft, Petter Hersleth, Statkraft

Synergi offshore vind, olje og gass, Sjefsforsker Finn Gunnar Nielsen,
StatoilHydro

Company History:

- Established in 2000 for marketing of large wind turbines (3.5 MW) based on own design
- R&D project consisting of technology development and testing of full scale prototypes under realistic operational conditions at Hundhammerfjellet Wind Park on the Norwegian coast – one of the most extreme wind park sites in the world
- Field testing 2003-2007 with very positive results
- Ready for serial production 2008

2

Vision, Mission and Business Case:

Vision

Reliable energy for a clean future

Mission

ScanWind shall be a recognized developer and supplier of wind turbines and services for the coastal onshore and the offshore markets

Business Case

Developing, manufacturing, installing, marketing, and maintenance of wind turbines

Dedicated suppliers and partners

Primary markets are the coastal onshore and the offshore markets in Northern Europe

3

ScanWind locations

- **Trondheim**
  - **ScanWind Group AS**
  - **Head office, administration, sales & marketing & support.**
  - **12 employees**
- **Verdal**
  - **ScanWind Vindkraft AS**
  - **Outfitting and assembly workshop**
  - **18 employees + 15- 25 hired staff on project basis**
- **Karlstad**
  - **ScanWind Vindkraft AB**
  - **Technology and engineering**
  - **9 employees**

4

5

ScanWinds deliveries and orders:

- **4 WTG prototypes delivered to Hundhammerfjellet – NTE**
- **7 WTGs installed at Hundhammer-fjellet in 2007.**
  - **Turbine 5-11: 3.5 MW PM-generator. Electrical system: AWP/Switch**
- **4 WTGs currently under outfitting. Field installation at Hundhammerefjellet in Q2 2008 with handover in Q3 2008.**

6

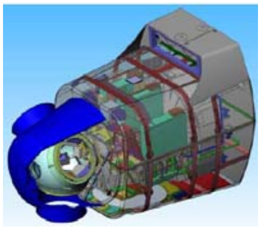
Generator

- Permanent magnet generator
- Variable speed optimize the turbine for maximum efficiency in the entire operating range with possibility to produce electricity as low as ~2 m/s
- The stator is arranged in 12 segments i.e. 3 parallel generators
- The generator operates virtually without cogging, which leads to reduced fatigue loads compared to conventional turbines.
- The generator can be run as a motor, which makes accurate positioning possible for maintenance purpose

7

Construction details

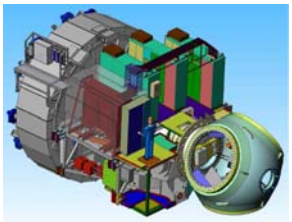
- SW3500 DL is designed for optimal material use and is the lightest direct drive turbine in the multi MW class
- It is constructed for IEC Wind Class 1A
- The turbines are constructed for modular assembly
- Yaw and Pitch systems are constricted to limit the fatigue stresses in the turbine
- Yaw and Pitch systems are constricted to limit the maintenance need on bolted connections and critical welds
- Electric yaw and pitch
- Dimensioning loads are simulated in ScanWinds own simulation software – ScanLog and ScanSim



8

Power converter

- SW 3500 DL takes advantage of 100% frequency converter
- 3 converters are working in parallel
- Reactive power compensation by adjusting cosφ on each turbine
- Each turbine gives high energy quality to the grid, and can be used in weak rural grids
- The main power transformer is of the epoxy casted type (GEAFOL) and is adapted especially for the wind power industry.



9

Lifting equipment

- ScanWinds own lifting equipment is designed for installation of large WTGs in challenging mountain terrain.
- The lifting equipment enables WTGs installation in relatively high wind (15 m/s) with increased safety compared to conventional methods using big cranes.
- The lifting equipment occupies a minimum of ground area, and reduces the environmental impact on the surrounding area.
- The lifting system requires no anchoring in the terrain.

10

Product reliability:

- SW 3.5 MW has evolved in 3 generations over the last 7 years from Demo 1.
- Problems in Wind turbines are:

Turbine part	Market total Wear or Fail units 2006	Downtime due to W/F in hours	Downtime %	SW index relative to market
Gear boxes	130	15 857	19.6%	0
Generators	184	18 745	23.1%	0.6
Rotor / blades	195	8 704	10.7%	0.8
systems	203	6 729	8.3%	0
Electric system	611	14 369	17.7%	0.8
Electric controls	174	2 742	3.4%	0.8
Pitch	345	7 297	9.0%	1.0
Yaw system	132	3 495	4.3%	1.0
bearing	27	3 141	3.9%	1.0
Total	2 001	81 079	100%	67%

Data from Wind Stats. The table show the number of units that stopped due to ware or failure in Germany in 2006. 18075 units were operating on average in Germany in 2006.

Conclusions:

- Maintenance costs and warranty provisions estimated at 67% of market average.
- Availability estimated to be 1-2% higher than market average.

11

Specifications generation 3; SW 3.5 MW 90m:

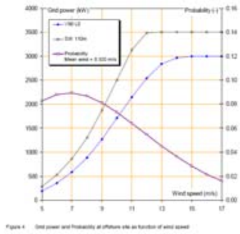
- Rated power : 3,5 MW
- Turbine diameter : 90 meters
- IEC class : 1A
- Generator : Direct driven, permanent magnet
- Blades : 3
- Blade Speed : 11-22 rpm
- Cut-in Wind : 3,5-4 m/s
- Cut-out Wind : 25-29 m/s
- Control : Pitch & momentum control
- Operational speed : 13-17 m/s
- Pitch system : Individual electric
- Yaw system : Electric
- Electric system : 690V / 22kV, frequency conversion
- Est. Prod. Capacity :12.8 GWh per unit/yr, 97 % availability, wind profile Hundhammerfjellet

12

ScanWind Approach:

- **Market strategy: Focus on markets with high wind speeds and rough conditions:**
  - **Costal onshore: IEC 1B – marketing from 1Q 2008**
  - **Offshore: IEC 2B – marketing from 4Q 2008**
- **Product strategy: Build on existing platform + cost optimalization:**
  - **Generation 3: SW 3.5 MW with 90m blades**
  - **Generation 4: SW 3.5 MW**
    - 100m onshore IEC 1B – delivery from 2010
    - 110m blades IEC IIB – delivery from 2011 (offshore)
  - **Generation 5: SW 4.2 MW with 120 blades (appr. +20% production)**
- **After 1-2 years: Evaluate new technology platform.**

Power Curve Comparisons



Annual energy yield at mean wind 8.5 m/s

V90 L0	10.71	GWh/year
SW 110m 3.5 MW	14.29	GWh/year

- **SW turbines produce 30% more energy per year than our competitors in the offshore market**

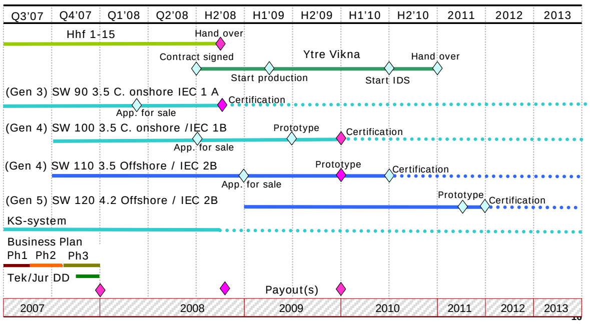
14

Conclusion product performance :

- **SW turbines produce 15% more energy per year than our competitors in the wind class IEC 1 coastal onshore market.**
- **SW turbines produce 30% more energy per year than our competitors in the offshore market.**
- **SW has estimated maintenance costs and warranty provisions for the SW 3.5 product family to be 67% of the marked average and to have increased availability of 1-2% as compared with the marked average.**

15

Business plan:



Scan Wind

19

Scan Wind

www.scanwind.com

21

Scan Wind

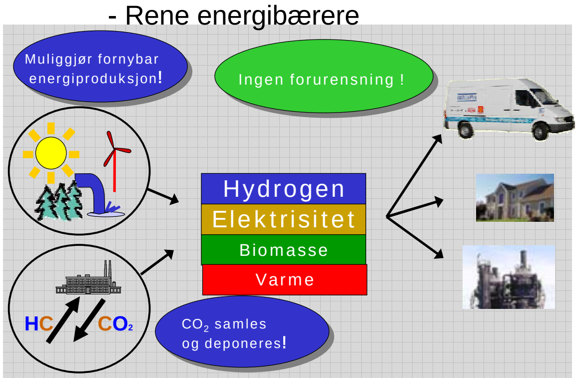
TAKK FOR MEG!

RELIABLE ENERGY FOR A CLEAN FUTURE

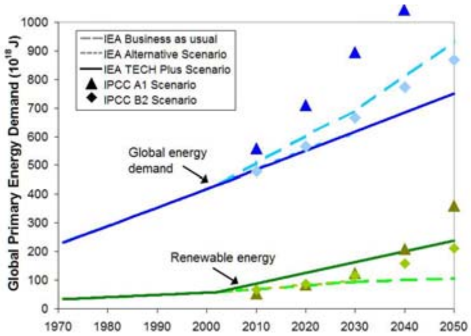
22

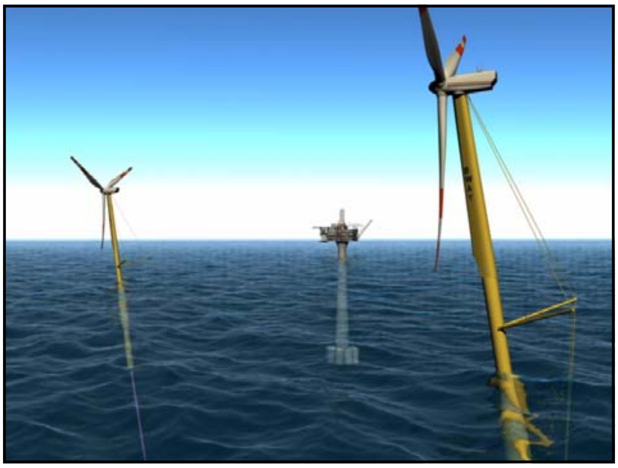
REN ENERGIKJEDE

- Rene energibærere



Klimautfordringens omfang





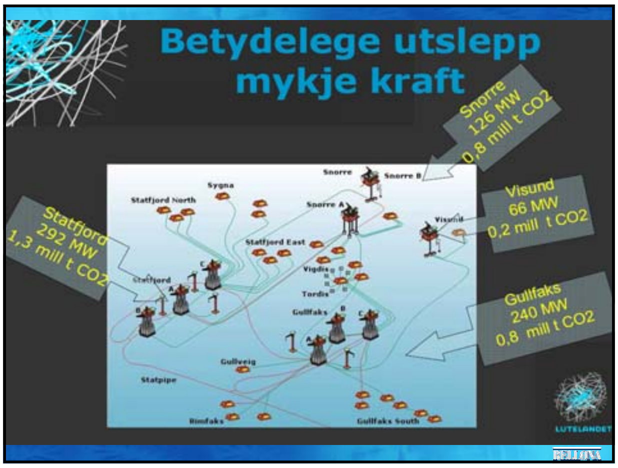
Kraftproduksjon på petroleumsinstallasjoner

- Variable kostnader med offshore gassturbin
  - Forutsetninger: CO2-avgift 342 NOK/tonn, NOx-avgift 15 NOK/kg:
  - Gasspris 2 NOK/Sm3: 0,95 kr/kwh
  - Gasspris 1,3 NOK/Sm3: 0,76 kr/kwh
  - Kabelinvkost: sørlig nordsjø 3 mrd 142 MW
  - INKLUSIVE LOKALE

Effektbehov - eksempler

- Totalt energiforbruk: 50 TWh gass
- Totalt kraft og mekanisk energi: 16 TWh
- Norskehavet: 336 MW / 147 MW,
  - Draugen: 36/27 MW -
  - Heidrun: 60/34 MW
- Osebergområdet: 300 MW / 137 MW
  - Oseberg FS 165 / 37 MW
  - Oseberg C 32 / 32 MW
- Gullfaks A: 96 MW / 47 MW
- Gullfaks C: 67 MW / 35
-
- Ekofiskområdet: 269 MW / 95 MW
  - Ekofisk J 101 / 26 MW

Troll: 108 MW / 32 MW



OD/NVE/SFT/PTIL - Elektrifiseringsstudie

Tabell 9: Hoveddata for elektrifisering av områder på sokkelen med kraft fra dedikert produksjon

Område	Tiltakskostnad (kr/tonn)	Samlet investeringsanslag (mrd. kr)	Samlet netto CO_2-reduksjon (mill. tonn)
Sørlige Nordsjø	1 600	8,6	6,2
Midtre Nordsjø	3 800	6,2	2,3
Nordlige Nordsjø	*1 550*	*23,2*	*16,3*
Nordlige Nordsjø 50Hz	2 550	8,3	4,4
Nordlige Nordsjø 60Hz	1 600	16,7	11,7
Norskehavet	1 900	11,9	7,9

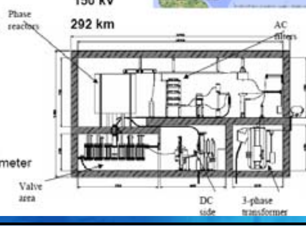
Valhall

Operator: BP

Partners: Amerada Hess, Shell, Total

Technical Data

Commissioning year:	2009
Power rating:	78 MW
AC Voltage:	300 kV / 11 kV
DC Voltage:	150 kV
Length of DC cable:	292 km

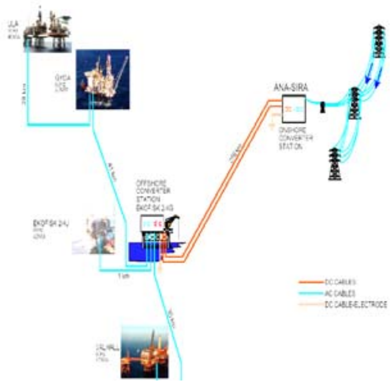


LxWxH = 22x15x13 meter

ABB

Investeringer i
Infrastruktur
sørlig nordsjø,
(kabel fra land 1
Mottak og forde

= NOK 3 mrd



Elektrifisering kun basert på vind (uten kabel til land)

- Krever opprettholdelse av gass/diesel
  - M.A.O, mindre gevinster knyttet til reduserte driftskostnader
  - Ingen fjerning av turbiner (sparte kostnader)
  - Men dermed heller ingen frigjort plass…
- Installasjoner med gassmangel interessant
  - Dieselkraft koster 2,5 ganger mer enn gasskraft
  - Kombinasjon med vindkraft kan redusere energikostnader

Elektrifisering basert på vind og kabel fra land

- Kabel sikrer effekt til plattform
- Vind dekker energibehovet
- Vindpark kan dimensjoneres for eksport til land
- Forutsetter toveis-kabel
- Kabelinvesteringen får lang levetid
- Plattform kan utgjøre infrastruktur for videre utvikling etter nedstengning av olje/gassproduksjon

Klimaforliket om virkemidler:

1. Forurenser betaler

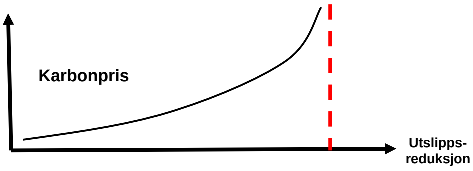
2. Avgifter og kvoter på 70 % av utslipp

2. Andre virkemidler kan kanskje være mulig

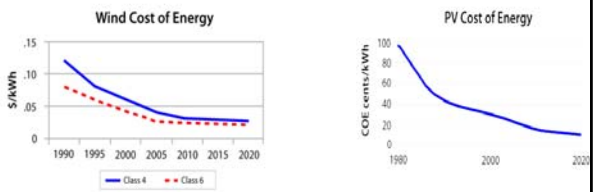
Konfliktlinjer i norsk klimapolitikk

Konfliktlinjer i norsk klimapolitikk

I stedet for en økende kostnadskurve…



…kan vi hjelp av læring og teknologiutvikling Innenfor nullutslippsløsninger få slike kostnadskurver

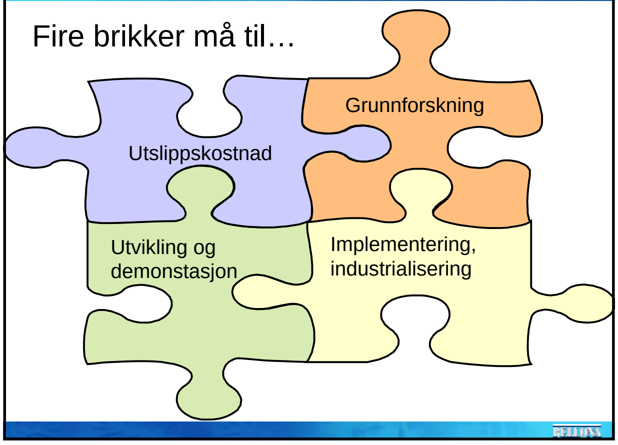


Kilde: US DOE

Barrierer mot nullutslippsløsninger

- **Behovet for kritisk masse**
- **Behov for kostbar infrastruktur**
- **Bratt lærekurve**
- **Grunnleggende teknologiskift**
- **Langsiktig finansiering**

Fire brikker må til…

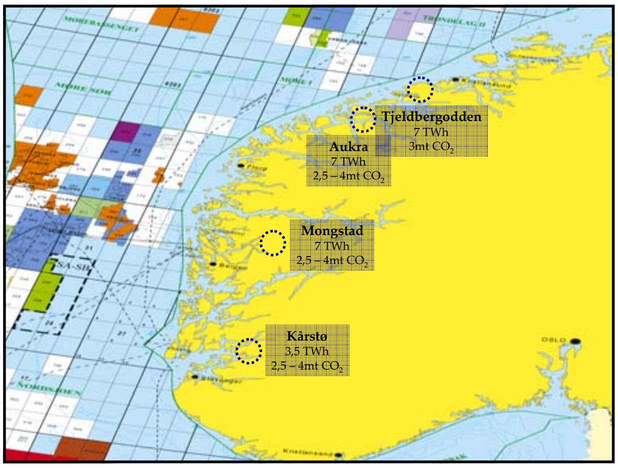


Steg 2: Testing og demonstrasjon

- Testsenter med nødvendig infrastruktur
  - Kabel
  - Transport
  - Fasiliteter
- Finansiering av fullskala piloter
  - Gassnova-modellen ?

Steg 3 kommersialisering

- Uavhengig av øvrige virkemidler, bør staten etablere kabelinfrastruktur, samt etablere knutepunkt for tilkobling i aktuelle områder
- Lovgrunnlaget for tildeling av areal m.m. må avklares
- Alternativ 1: Produksjonstilskudd 0,5-2 NOK/kWh
  - Konkurranseaspekt for å sikre framdrift – Størst tilskudd til de første?
  - Spesifikk tilskuddsats for ulike teknologier



Steg 3 kommersialisering

- Alternativ 3: Anbud/auksjon

"ENOVA SF skal på oppdrag fra OED inngå kontrakter for bygging av fornybar havenergi for årlig produksjon på 20 TWh innen 20?? – I den første anbudsrunden, som starter i år, ber vi om anbud på inntil 5 Twh"

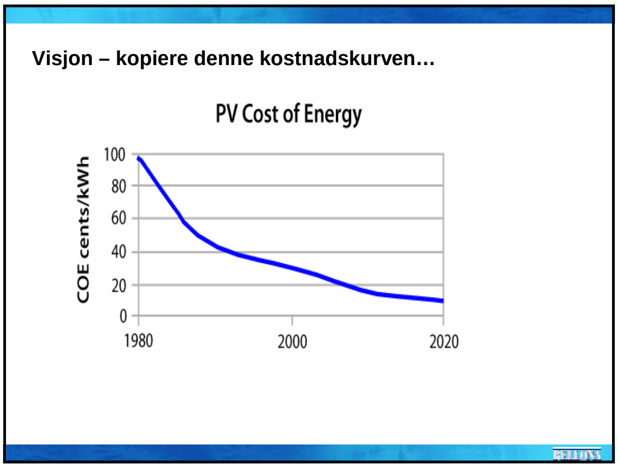
- Tildeling av areal kan være knyttet til anbud – muliggjør overordnet styring og skalafordel, også ved eventuelle små enkeltprosjekter

- Anbudsrunden må gi icentiver til kostnadsminimering, tempo og mangfold av aktører

Bellonas strategi

Kommersialisering:
- Forankre visjonen i Stortingsvalgprogrammene
- Skape konsensus blant aktører om ønskede virkemidler
- Forankre virkemidlene i neste "soria-moria"-erklæring

FOU/demonstrasjon:
- Klimaforliket gir et godt utgangspunkt
  - 150 millioner til offshore vind
  - 600 millioner til fornybar forskning
- Vår jobb blir å sikre faktisk gjennomføring


Visjon – kopiere denne kostnadskurven…
PV Cost of Energy
COE cents/kWh
100
80
60
40
20
0
1980
2000
2020

Offshore vindkraft i Statkraft

Petter Hersleth, Statkraft
25. Januar 2008

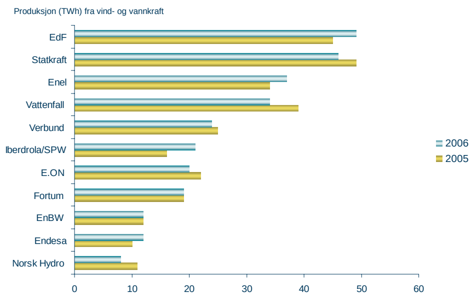
Statkraft
REN ENERGI

STATKRAFT

- Hovedkontor i Oslo
- Datterselskaper
- Europakontor
- Tilknyttede selskaper
- 158 vannkraftverk
- 3 vindparker
- Baltic Cable
- Gasskraft

Statkraft

LEDENDE INNEN FORNYBAR ENERGI



Statkraft

Kilde: Årsrapporter 2005 og 2006

INNOVASJON OG TEKNOLOGIUTVIKLING

- *Havenergi*
- *Saltkraft*
- *Vannkraft*
- *Solenergi*
- *CCS*
- *Thorium*
- *Bioenergi*

Statkraft

OFFSHORE VIND

Statkraft
REN ENERGI

STATUS OFFSHORE VIND

- Statkraft har ingen offshore vindparker i dag
  - Leter etter muligheter for å gjøre noe
  - Prosjekter må være kommersielle!
- Forbereder oss til offshore vind blir kommersielt tilgjengelig
  - Bedre teknologi og rammebetingelsene
- Vi deltar i mange teknologi- og forretningsutviklingsprosjekter
  - Bygger kompetanse internt og eksternt
  - Vurderer og utvikler nye og bedre forretningsmodeller
  - Teknologiutvikling

Statkraft

VÅRT FOKUS INNEN OFFSHORE VIND

- Norsjøbassenget!
- Der er andre land mer attraktive enn Norge
  - Rammebetingelser => kommersielt interessant
- I Norge er det behov for en dugnad
- I tillegg:
  - Vi har behov for å bygge kompetanse gjennom onshoreprosjekter
  - Vi må være forberedt på at det vil komme motforestillinger mot offshore vindkraft
    - Det er mange interessenter på havet også!

TEKNOLOGI OG FORSKNINGSPROSJEKTER

- Sway
- 1000 MW i 2012
- Chapdrive
- Havenergiprogram
- KMB: Deep sea offshore wind turbines
- Smartgenerator
- Supergrid
- Vann/vind potensialet
- Masteroppgaver

SWAY

Vindturbin plassert på en flytende tårnkonstruksjon
- Slank tårnstruktur med ballast, og tyngdepunkt under vannflaten
- Ballansepunkt over tyngdepunkt

Statkraft har deltatt i Sways teknologiutviklingsprosjekt sammen med Norges Forskningsråd, Shell og Lyse

Deltagelsen medfører at Statkraft har en liten eierandel i Sway

SWAY VINDPARK

1000 MW I 2012 – EN MULIGHETSSTUDIE

- En utfordring til nordiske aktører i hele verdikjeden
- Invitert til å løse følgende problemstilling
  - Hvordan bygge et offshore vindkraftverk
    - 1000 MW
    - teknisk tilgjengelig i 2012
    - grunt vann <60 m
    - >95% tilgjengelighet
    - løsning basert på state of the art

UTFORDRINGER OG MULIGHETER

- Utfordringer
  - Konstruksjon/bygging/masseproduksjon
  - Utplassering
  - Drift og vedlikehold
  - Teknologisk løsning
  - Fundamentering
  - Hvordan få strømmen til land
  - Konsesjonsprosesser
    - Regelverk
    - Internasjonalt samarbeid
- Muligheter
  - Dette er en ung bransje
    - Det er posisjoner som ikke er tatt
    - Forretningsmodellene er uklare
  - Stor vekst i dag og økende fremover
  - Av de fornybare energikildene som kan gi størst bidrag innen relativt kort tid
  - Teknologiutfordringer kan løses
    - Norge har kompetansen

HVORFOR?

- Dagens løsninger ikke er gode nok!
- Det kan være potensial for å bruke kjente løsninger på ny måte
- Kobling av aktører fra forskjellige fagmiljøer øker mulighet for nye løsninger
- Ikke inkrementell utvikling

Statkraft

side 13 STAKRAFT 2007

CHAPDRIVE

- Hydraulisk gir for vindturbiner
- Teknologiutvikling i NTNU-miljøet
- Statkraft deltar i BIP prosjekt i 2007 - 2008

Statkraft

side 14 STAKRAFT 2007

HAVENERGIPROGRAMMET

Overordnet

"Bygge Europas ledende kompetansenettverk innen havenergi. Målsettingen er at ny kunnskap vil initiere økt idétilfang som igjen gir grunnlag for nye konsept, nyskaping og bedre lønnsomhet."

Fakta

3 x universitet (NTNU, DTU, Uppsala) + Statkraft

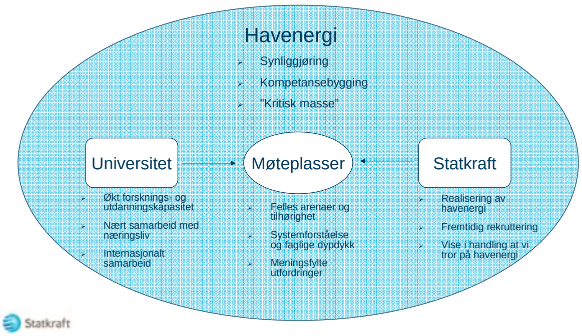
4 år med intensjon om forlengelse

64-80 millioner NOK fra Statkraft + tilsvarende fra universitetene

Statkraft

side 15 STAKRAFT 2008

HVORFOR HAVENERGIPROGRAM



Statkraft

side 16 STAKRAFT 2008

STATKRAFTS MÅLSETNINGER

2008

- Rekruttere toppkandidater (1 professor, 3 Post Doc, 7 PhD)
- Etablere arenaer og felles forståelse for målsettinger

2008-2012

- Minimum 11 + 11 = 22 PhD
- Minimum 22 mastergrader
- Etablert studentaktiviteter
- Inkludert andre relevante universiteter og industrielle aktører

Lang sikt

- Europas ledende kompetansenettverk innen havenergi
- Realisere havenergi basert på innovativ teknologi og kostnadsreduksjoner

Statkraft

side 17 STAKRAFT 2008

Status: Draft

Vindkraft FoU seminar
Trondheim 24- 25 January 2008

Synergy between offshore oil and gas industry and offshore wind

By Finn Gunnar Nielsen
Chief Researcher, StatoilHydro

StatoilHydro

2

This is StatoilHydro

- Established on 1 October 2007 following the merger between Statoil and Hydro's oil and gas activities
- 31,000 employees in 40 countries
- Offshore oil and gas experience:
  - …
  - The world's largest operator of deepwater fields

StatoilHydro

3

Energy - business and technology development

StatoilHydro

We had a dream ….

- Capture and store some of the energy around us:
  - without significant environmental consequences
  - make it work technically
  - at a reasonable cost

StatoilHydro

5

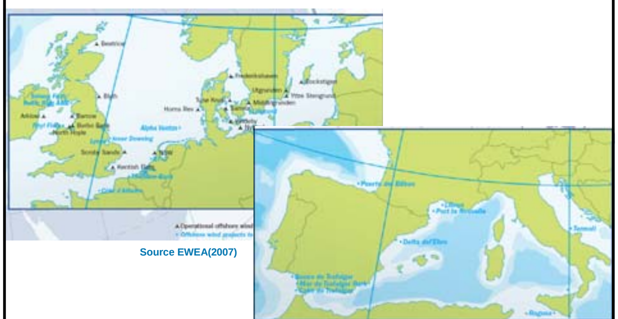
…and we invented the Hywind concept

- Combines proven technologies
  - Floating concrete sub-structure
  - "Off-the-shelf" offshore wind turbines
  - Water-depths >100 m
  - Inshore construction and assembly
  - Towed to site
  - Moored by three lines easy hook-up
- Designed for extreme conditions
  - H_s > 14m
  - U_{10} > 40 m/sec
- Potential
  - Power to offshore installations
  - Power to grid, Norway and internationally
- Demo to be installed in 2009
  - West of Karmøy
  - 2.3 MW Siemens WP turbine

StatoilHydro

6

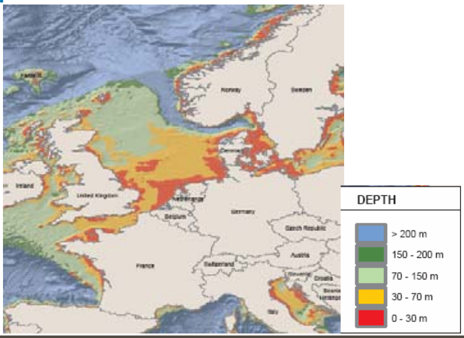
Present location of offshore wind farms



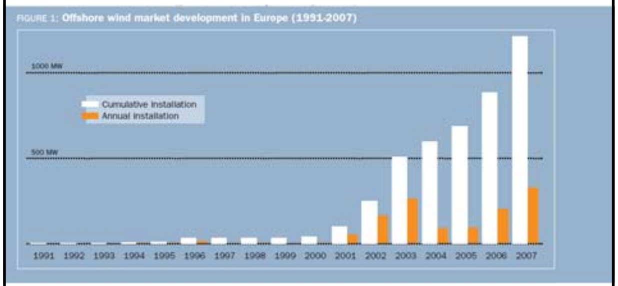
Source EWEA(2007)

StatoilHydro

Water depths

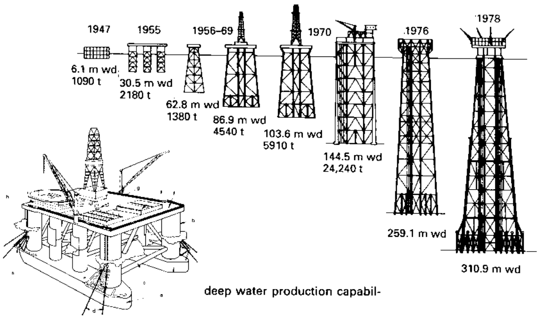


Installed offshore wind power capacity

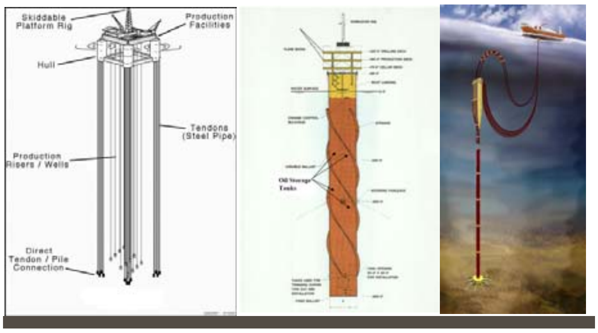


Source EWEA(2007)

The offshore oil industry 60 years ago



New approaches - Handling wave induced dynamics



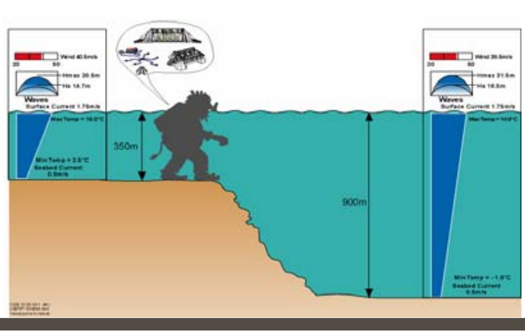
“New” materials

Design for harsh environment

- Environmental data
- Understand loads and responses
- Material requirements
- Standards and “best practice”

13

From Troll to Ormen Lange - A step into the deep.



StatoilHydro

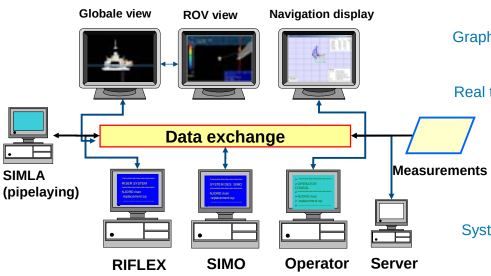
14

Template installation – August 2005

StatoilHydro

15

Simulation of marine operations – coupling 30 years of computational experience



Graphical interface

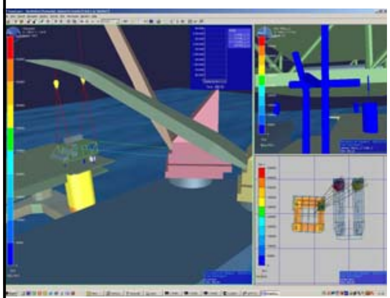
Real time coupling

System analysis

StatoilHydro

16

Complex marine operations

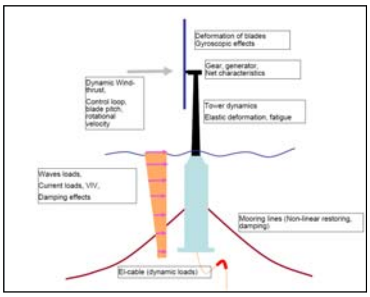


- •Wave, wind and current loads
- •Multibody dynamics
- •Structural and hydrodynamic interaction
- •Strongly non-linear
- •Active control
- •…

StatoilHydro

17

Dynamic effects – floating wind turbine



Three levels of modelling:

•Simplified hydrodynamics and turbine dynamics

•State of art hydrodynamics, simplified turbine

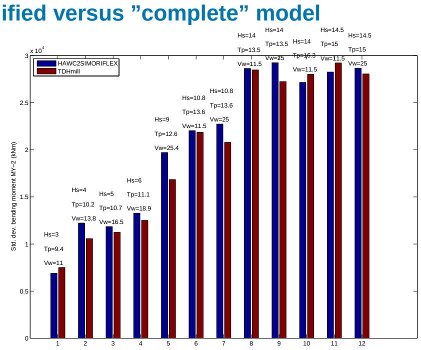
•State of art hydrodynamics and turbine

(SIMO /RIFLEX – HAWC2)

StatoilHydro

18

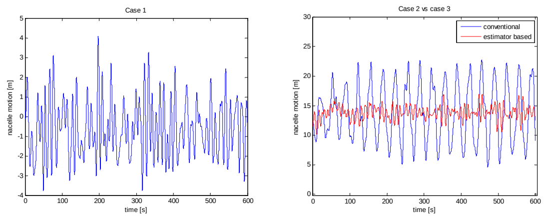
Simplified versus ”complete” model



StatoilHydro

19

Importance of control system
Horizontal nacelle motion



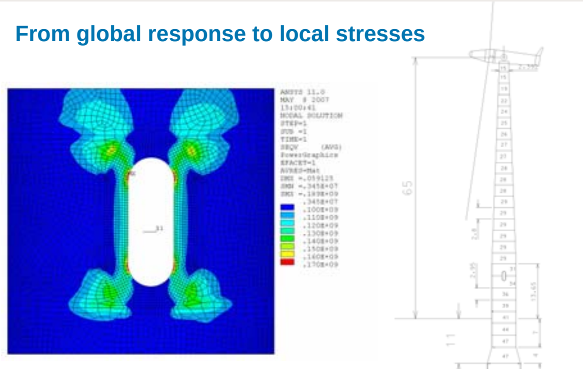
Hs = 5m, Tp = 12s, Um = 0 m/s,

Hs = 5m, Tp = 12s, Um = 17 m/s,

StatoilHydro

20

From global response to local stresses



StatoilHydro

21

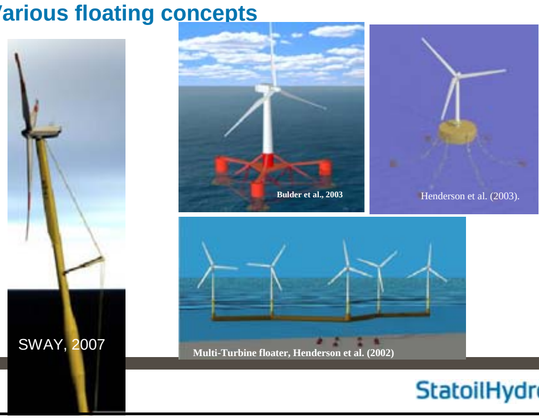
Recent solutions - Blue H - a 6 leg TLP

Blue-H, Dec 2007

StatoilHydro

22

Various floating concepts



StatoilHydro

23

Offshore wind turbine installation

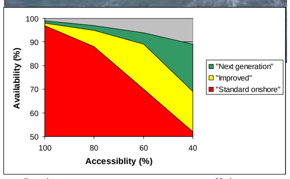
StatoilHydro

24

Operation in harsh environment. Importance of accessibility & reliability

- Reliability (failures / year)
- Maintainability (ease of repair)
- Serviceability (easy of service)

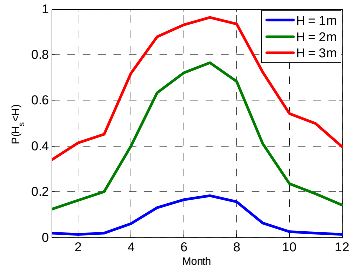
Need improved reliability and accessibility! (Figures for illustration only)



Onshore – remote offshore

StatoilHydro

Access, wave height limitations



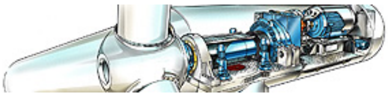
Fraction of time the significant wave height is less than H
Northern North sea 1973 – 1999.

Advanced access systems under development, e.g. Ampelmann (2006) TU Delft

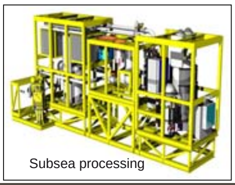
- From flight simulator to offshore wind.

Floating offshore wind turbines – Similarities to offshore oil and gas

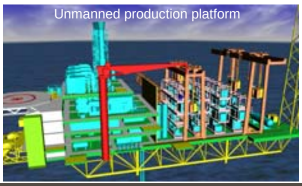
- Remote operations
- Need for high reliability
- Power transmission
  - Long distance
  - Dynamic cables
- Project execution



Source: Siemens Wind Power



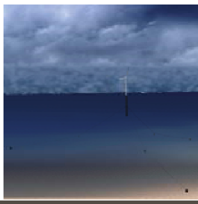
Subsea processing



Unmanned production platform

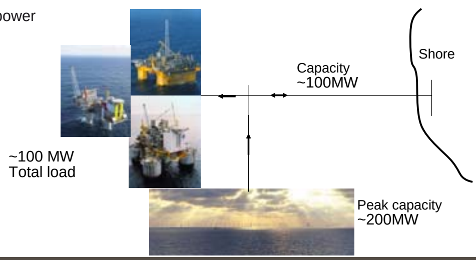
Floating offshore wind turbines – Important differences compared to offshore oil and gas.

- Number of units – one of a kind versus mass production.
- Access system
- Economy more sensitive to O&M costs
- Less safety concerns

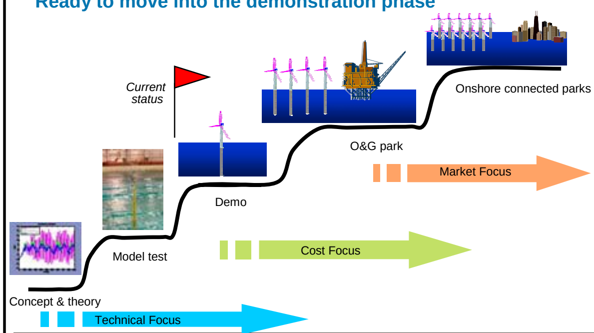


Vision

- Share infrastructure; Power to shore and platforms.
- Reduce emission to air
- New clean power



Hywind - from idea to commercial concept – Ready to move into the demonstration phase



Summary

- Design and operation of offshore wind farms is a young industry.
- Many similarities to offshore oil & gas activities
- Computational tools, design principles and experiences can be utilized
- Knowledge about design for and operation in harsh environment is critical
- Project execution experience can be utilized
- Important difference: Number of units
- Focus on accessibility and reliability

StatoilHydro

Offshoreteknologi – FoU resultat

Modellering av flytende vindkraftverk, Forskningssjef Frode Meling, MARINTEK

Løsninger for et 100 m vindturbinblad, PhD student Jørg Høyland, NTNU

Individuell pitch av vindturbinblader, PhD student Fredrik Sandquist, NTNU

Hydraulisk gir for vindkraftverk, Svein Kjetil Haugset, ChapDrive

Stabilisering av flytende vindturbiner, PhD student Thomas Fuglseth, NTNU

FEM Analysis of the NREL Phase VI Wind Turbine Blades,
PhD student Haiyan Long, NTNU

Simulering av flytende offshore vindturbin, forsker Andreas Knauer, Institutt for energiteknikk

Drift og vedlikeholdsoppfølging av vindkraftverk, Forsker Arnt O. Eggen, SINTEF Energiforskning

"Modellering av flytende vindkraftverk"

Vindkraft FoU Seminar 24/01-2008

Ivar Fylling - Sjefsingeniør "Offshore hydrodynamikk"
Frode Meling - Forskningssjef "Marine operasjoner og simulering"

MARINTEK Skip og havlaboratoriet

"DSOWT" Task 1: Design tools

- Develop a tool box (analytics, numerical methods and experiments) for the design of offshore wind energy concepts.
- Numerical and experimental activities will be conducted.
- Model development from scratch is not intended; rather coupling and modification of existing models are foreseen

---

Activities 2007

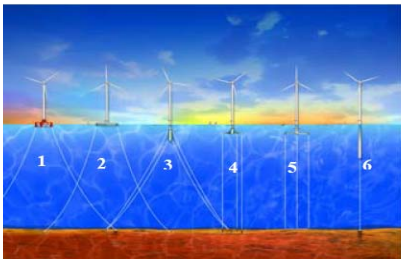
- Description of state-of-the-art modelling tools and know-how
- Evaluation and selection of tools for further development and coupling

Activities 2008

- Implementation of enhanced wind model
- RIFLEX-C – BEM model coupling
- ...

Floating WTs are on conceptual stage

Many publications with ideas and conceptual studies.
Wide range of floater and mooring solutions
Single- and multi-turbine proposals.

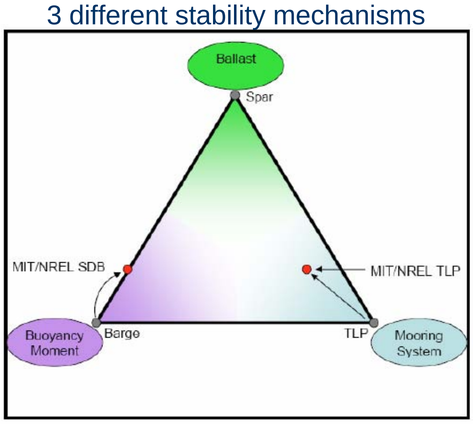


Design problem for floating turbines

- 'EXPERIENCE': The 'payload' of most floating offshore structures is located just high enough to survive extreme wave conditions.
- The payload of a wind turbine is 80 – 100 m above the sea.
- This is a great design challenge with respect to stability and dynamic behaviour.
- The angular motion about horizontal axes (denoted vessel pitch) will interfere with the turbine thrust force.

---

3 different stability mechanisms

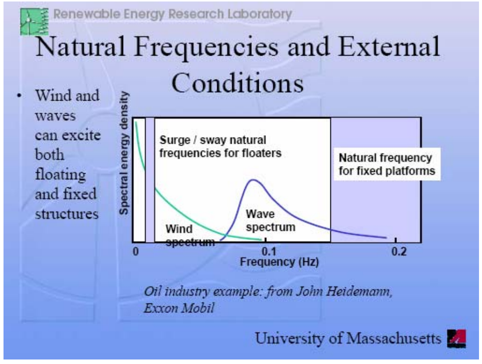


Dynamic characteristics

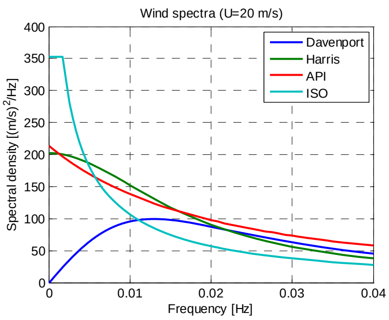
- Wave frequency responses, 5 – 20 s period
  - Wave potential forces, inertia and damping
  - Hydrostatic restoring force
- Low frequency responses, 30 – 180 s period
  - 2nd order wave forces
  - Wind- and current forces, VIM
  - Mooring system
- High frequency forces 1 – 5 s period
  - Nonlinear hydrodynamic forces, VIV
  - Structural stiffness

MARINTEK SINTEF

Illustration of frequency ranges



MARINTEK SINTEF



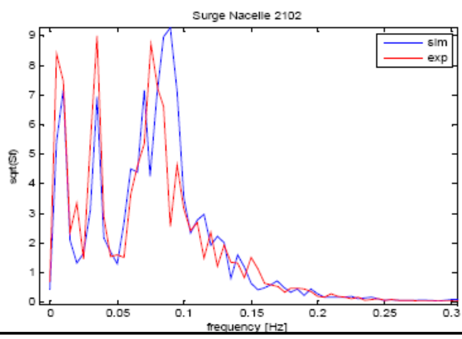
MARINTEK SINTEF

Simulation, floating WT

- A wide variety of design codes for wind turbines
- Little has been done for floating turbines, examples:
  - Drijfwind, concept screening
  - ADAMS
  - FAST (+ WAMIT) , MIT
  - Hawc2+SIMO+RIFLEX

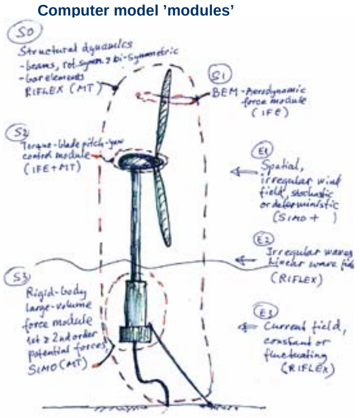
MARINTEK SINTEF

Hawc2-SIMO-RIFLEX simulation vs model tests



MARINTEK SINTEF

Computer model 'modules'



MARINTEK SINTEF

Strategy for simulation tool development

- •Use existing software package
- •Add functionality to this as necessary
- •RIFLEX-C, the coupled version of RIFLEX and SIMO
- •This package, in its present form, handles
  - •wind, wave and current loadings on the floating structure
  - •Mooring line and umbilical behavior as an integral part of the analysis
  - •Calculation of rigid-body motions and elastic deflection og beam structures.
- •To be added (work 2008)
  - •Multi-point wind-models to cover the propeller disk
  - •BEM load module
  - •Blade pitch controls, yaw control
  - •Model the mechanical load from the gear & generator (Moment control).
- •Emphasis will be put on making the additions modular (i.e. using DLL interfaces).

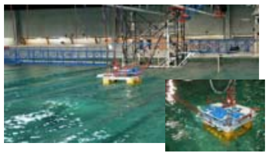
MARINTEK Verification tests, examples

West of Africa buoy

Snorre II (B) in Norway

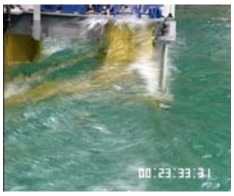
Terra Nova Project in Canada

Thunder Horse, Gulf of Mexico

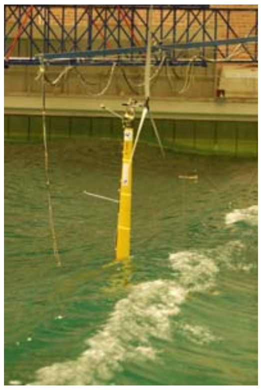


Wave impact loads on fixed and floating structures

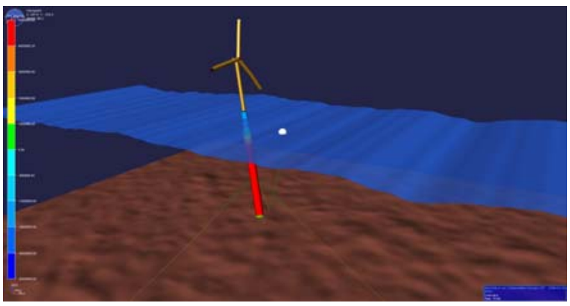
JIP (2007-2009): *Wave Impact Loads*



Renewable energy



Visualization example – RIFLEX-C ++



Teknologiskifte for store vindturbinblad

Presentasjon av PhD-stud

Jörg Höyland

jorg.hoyland@ntnu.no

NTNU

Introduksjon
Større vindturbiner
Materialer
Datamodell

Veiledere: Andreas Echtermeyer
Nils Petter Vedvik

Start: April 2004
Ferdig: August 2008

NTNU

Introduksjon
Større vindturbiner
Materialer
Datamodell

Offshore
Utfordringer

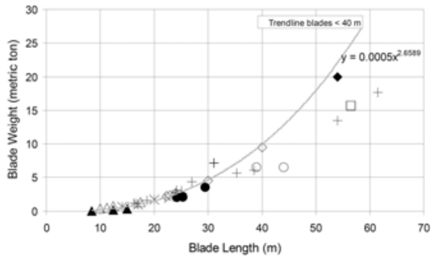
Installasjonskostnader offshore

NTNU

Introduksjon
Større vindturbiner
Materialer
Datamodell

Offshore
Utfordringer

Bladets masse



NTNU

Introduksjon
Større vindturbiner
Materialer
Datamodell

Offshore
Utfordringer

Bladets utbøyning

NTNU

Introduksjon
Større vindturbiner
Materialer
Datamodell

Offshore
Utfordringer

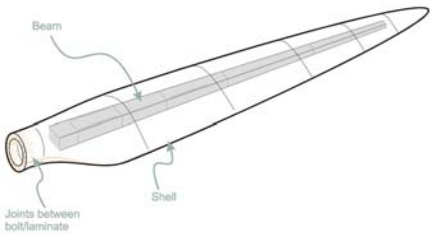
Problemstilling

- Hvordan lage større vindturbinblad?
- Inkrementell utvikling?
- 150m langt blad… ta et stort steg
- Bedre materialer – testing & design

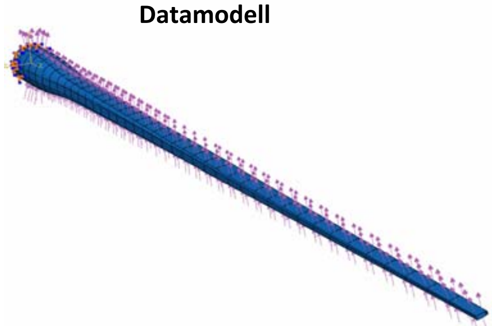
NTNU

Testing av komposittmaterialer

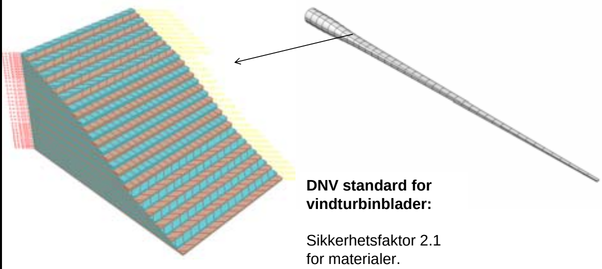
Bladets oppbygging



Datamodell



Definere materialer

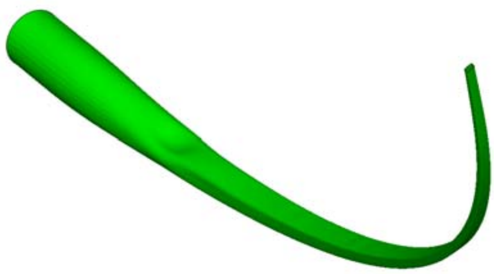


DNV standard for vindturbinblader:

Sikkerhetsfaktor 2.1 for materialer.

Analyse av spenninger

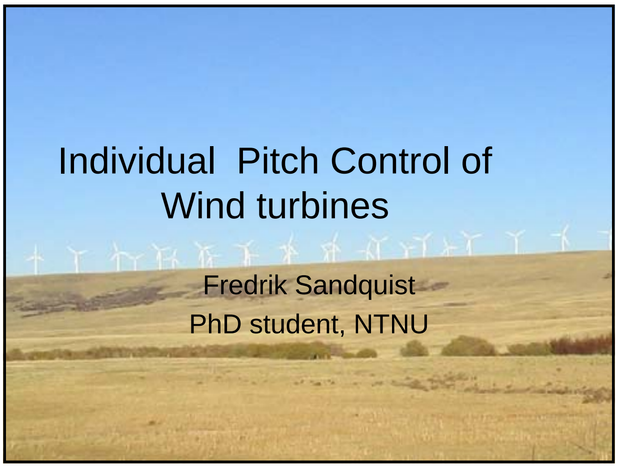
Analyse av stabilitet (bukling)



- Standard setter to krav:
  - *Styrke* (bukling kritisk)
  - *Utbøyning* (stivhet kritisk)
- For et 100m blad vil krav til stivhet føre til unødvendig tung løsning.
  - Ikke nødvendig krav ved pitch-regulert blad → oppdatere standard
- Optimert for styrke
  - Skal teste optimert design og material løsning.

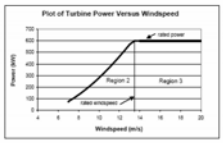
Konklusjon

- **Forståelse og optimering av materialers produksjonsprosess.**
- **Realistisk FEM-modell for design**
- **Stivhetsdominert løsning**
  - Oppdatere standard?
- **Styrkedominert løsning**
  - Testes



Variable Speed Pitch Controlled Wind Turbines

- Control inputs
  - Blade pitch angles
  - Turbine torque
- Operation regions
  - Region 1, 2 and 3



Control Strategies

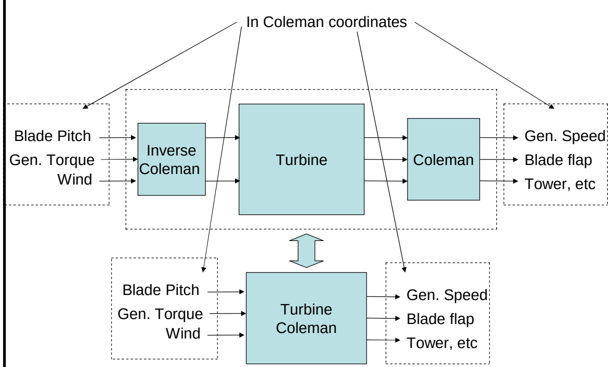
- Region 2: Maximum power
  - Constant tip speed ratio
  - Collective pitch constant
  - Variable torque
- Region 3: Constant speed and power
  - Variable pitch
  - “Constant” torque

Load Reduction

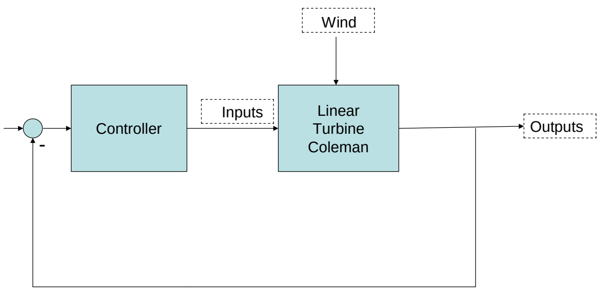
- Load reduction
  - Drive train
  - Blade load, mostly flap
  - Tower
- Loading
  - Gravity
  - Wind
- Periodic loading
  - Gravity
  - Wind shear
- Almost periodic loading
  - Wind gusts

Method

- Nonlinear aero elastic dynamic model of the entire turbine
- Linearize the model around an operation point
  - Azimuth varying linear model
- Apply the Coleman transformation on the linear model
  - (Almost) time invariant linear model
- Apply multivariable control theory on the linear model

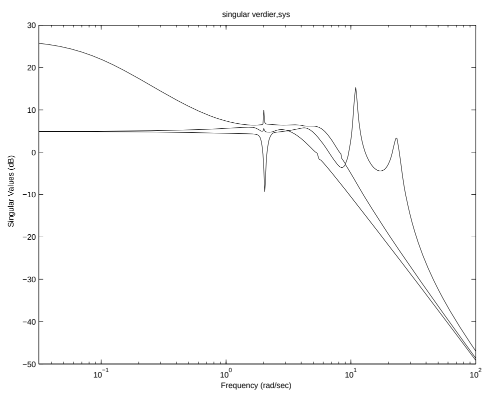


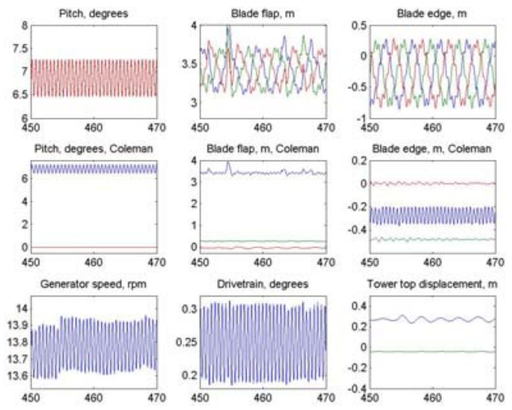
Design a LQG controller

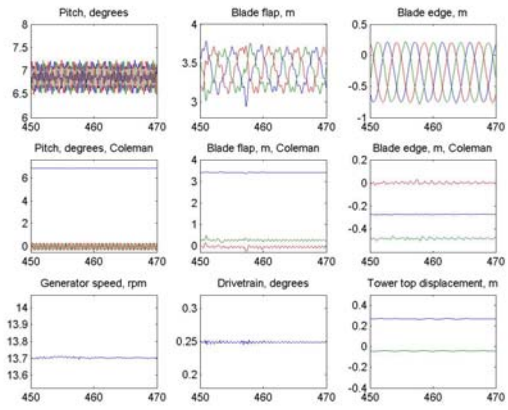


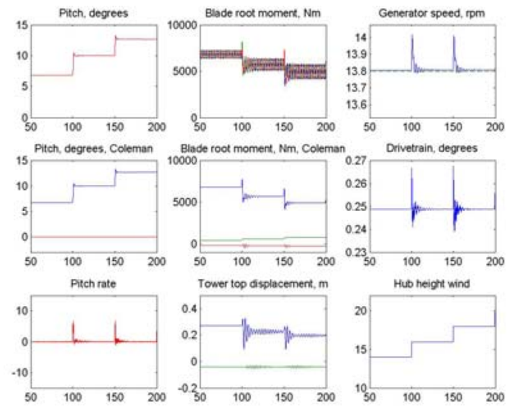
LQG

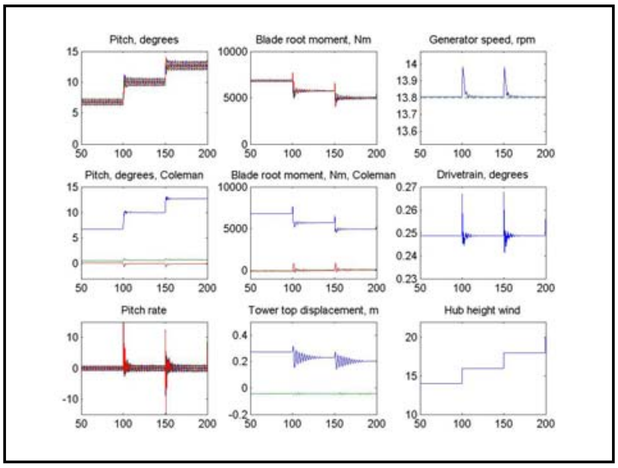
- Easy to use
- The static error is zero because of the integrators
- Easy to change the measured signals
- Measured blade flap or blade moment and generator speed in the individual pitch controllers

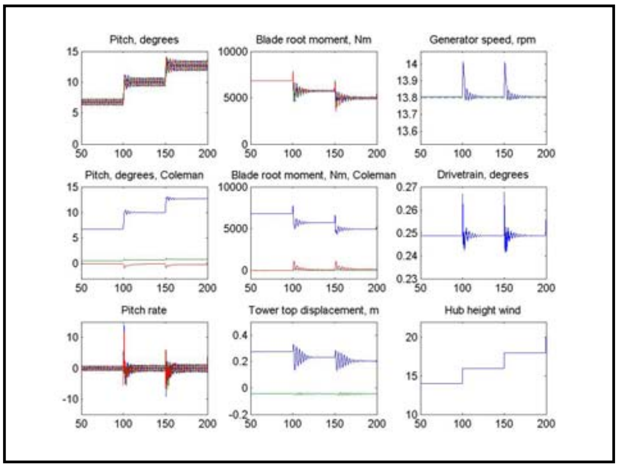


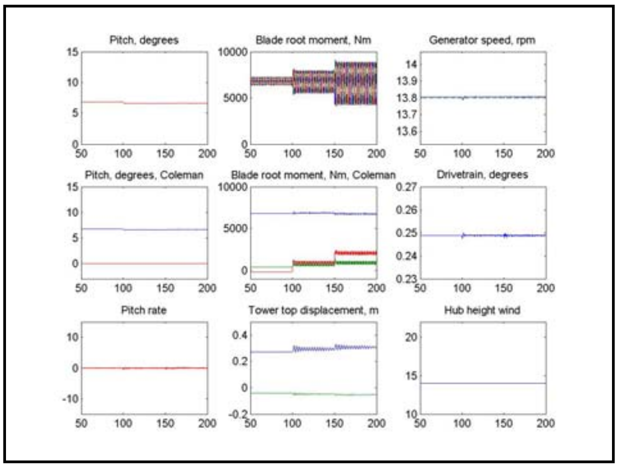


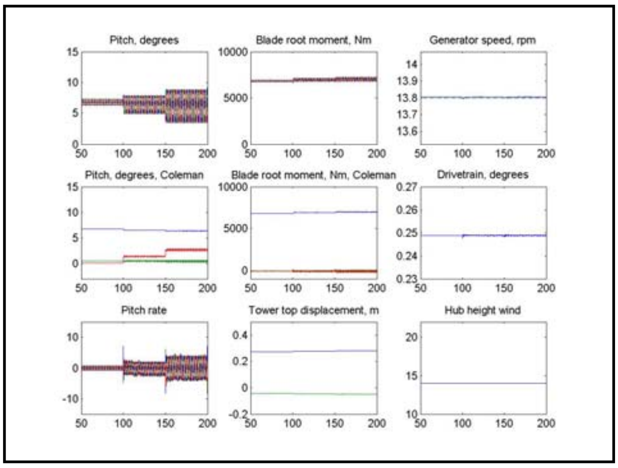


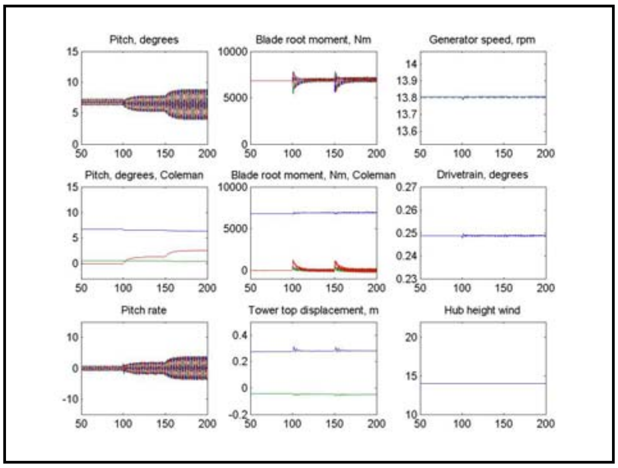


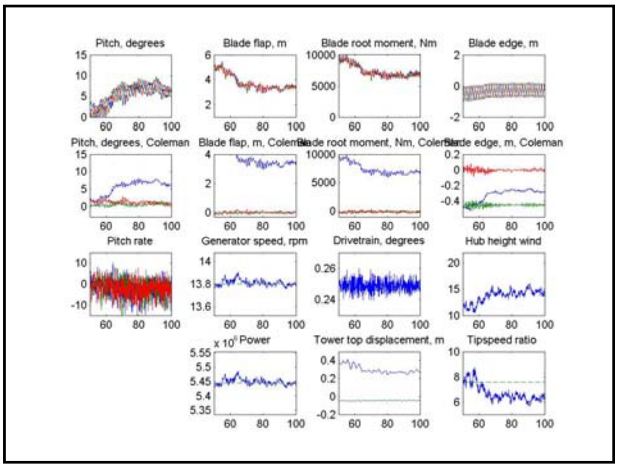

Pitch, degrees
Blade root moment, Nm
Generator speed, rpm
Pitch, degrees, Coleman
Blade root moment, Nm, Coleman
Drivetrain, degrees
Pitch rate
Tower top displacement, m
Hub height wind

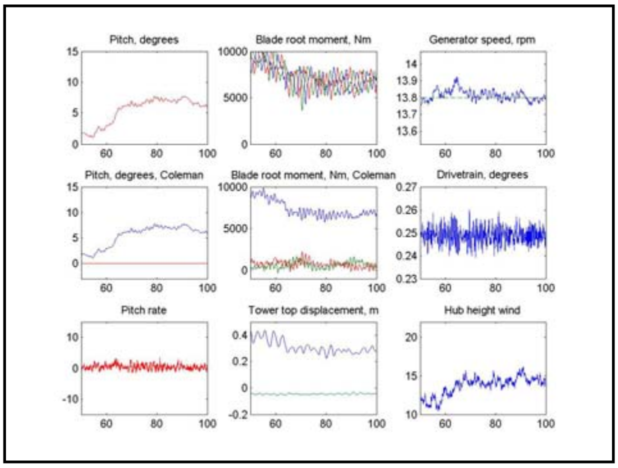

Pitch, degrees
Blade root moment, Nm
Generator speed, rpm
Pitch, degrees, Coleman
Blade root moment, Nm, Coleman
Drivetrain, degrees
Pitch rate
Tower top displacement, m
Hub height wind

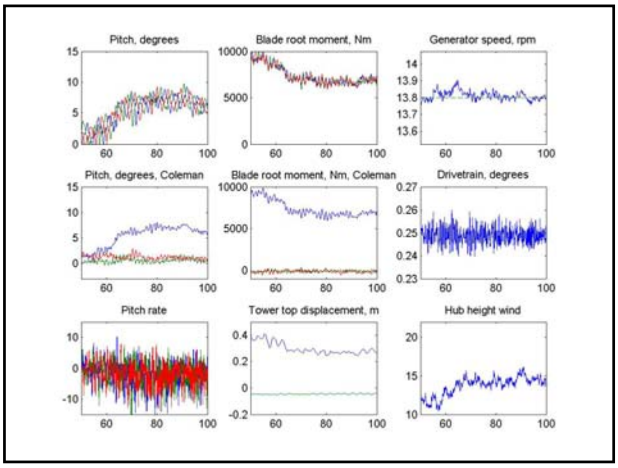

Pitch, degrees
Blade root moment, Nm
Generator speed, rpm
Pitch, degrees, Coleman
Blade root moment, Nm, Coleman
Drivetrain, degrees
Pitch rate
Tower top displacement, m
Hub height wind

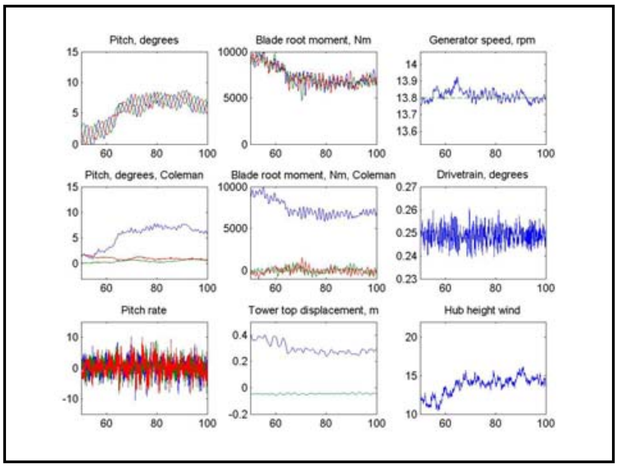

Pitch, degrees
Blade root moment, Nm
Generator speed, rpm
Pitch, degrees, Coleman
Blade root moment, Nm, Coleman
Drivetrain, degrees
Pitch rate
Tower top displacement, m
Hub height wind


Pitch, degrees
Blade root moment, Nm
Generator speed, rpm
Pitch, degrees, Coleman
Blade root moment, Nm, Coleman
Drivetrain, degrees
Pitch rate
Tower top displacement, m
Hub height wind


Pitch, degrees
Blade flap, m
Blade root moment, Nm
Blade edge, m
Pitch, degrees, Coleman
Pitch rate
Generator speed, rpm
Drivetrain, degrees
Hub height wind
Power
Tower top displacement, m
Tipspeed ratio







Research Problems

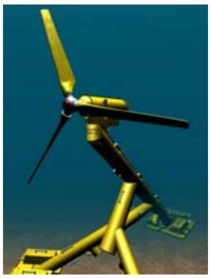
- Best model for control analysis?
- Which signals can and should be measured?
- Limitations?
- Make and analyze controllers

Hydraulisk gir til vindturbiner

Svein Kjetil Haugset
ChapDrive AS

Bakgrunn

- Tidevannsturbinen i Hammerfest
  - Rotordiameter: 20 meter
  - Generatoreffekt: 300 kW
  - Turtall på generatoren: 500 rpm
  - Turtall på turbinen: 7 rpm
  - Utvekslingsforhold: 1:70
- Størrelse og vekt på girboks inspirerte til nytenking
  - Ideen om hydraulisk girboks til tidevannsturbiner ble unnfanget
  - Fokuset skiftet gradvis til *vindkraft*

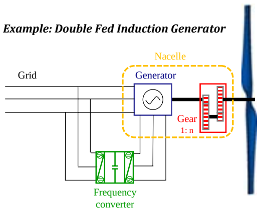


Dagens løsning:

Mekanisk gir:

- Generator plassert i nacellen
- Fast gir utveksling:
  - Turbinhastighet styrt av generator *eller*
  - Frekvensomforming

Example: Double Fed Induction Generator



Problemer:

- Høy vekt i nacellen:
  - Høy installasjons kostnad
  - Høy vedlikeholdskostnad
  - Lav egenfrekvens på konstruksjon
- Mekaniske girbokser står for ~30 % nedetiden
- Girbokser skiftes hyppig

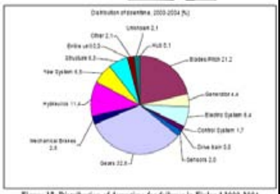
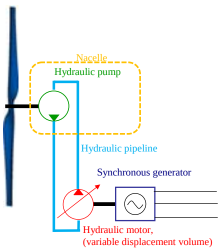


Figure 17: Distribution of downtime for failures in Finland 2000-2004
Source: Tuulivoiman Tuotantotilastot Vuosiraportti 2000-2004

ChapDrives løsning



Hydraulisk gir:

- Generator plassert på bakkenivå
- Variabel utveksling som gir:
  - Optimal hastighet på turbinrotor *og*
  - Synkronhastighet på generator

Fordelene med hydraulisk gir

- **Generator**
  - **Lavere installasjons og driftskostnader**
  - **Lettere konstruksjoner pga. høyere egenfrekvens**
  - **Reduserer ballastvekten på flytende offshore turbiner**
- **Forbedret drift av vindturbiner**
  - **Større pålitelighet**
    - **Smøring**
    - **Transporterer varme: Kjøling**
    - **Demping av effektvariasjoner fra turbinen**
    - **Enklere å skifte komponenter , gir bedre mulighet til å designe systemet til ønsket levetid**
  - **Standardiserte komponenter med kjente egenskaper.**
  - **Rask regulering og kort responstid.**
    - **Treghetsmomentet er lite; ofte regnet 72/1 i forhold til en elektromotor med samme effekt**
  - **Mulighet for synkrongenerator direkte koblet på nett**
    - **Rimeligere generatorer**
    - **Ikke behov for frekvensomformere**
    - **Ingen reaktiv effekt til nette**
- **Bedre virkningsgrad og bedre kontroll på belastning**
  - **Konstant TSR gir god virkningsgrad over et stort driftsområde**
    - **Vil lett oppveie hydraulikkretsens lave virkningsgrad**
  - **Mulighet for å variere turtall gir bedre kontroll på belastning / effekt**
  - **Mulighet for hydraulisk brems**

Off-shore flytende turbiner

- Store turbiner – lav rotasjonshastighet
  - Behov for større utveksling som gi høyere vekt på gir *eller* sakteroterende generatorer
  - Øker behov for ballast
- Vanskelig tilgang for tilsyn og vedlikehold
  - Krever at komponentene har høy pålitelighet
- Tøffe forhold
  - Krever korrosjonsbestandig
  - Krever robusthet

Hydraulisk gir kan innfri disse kravene

ChapDrive AS

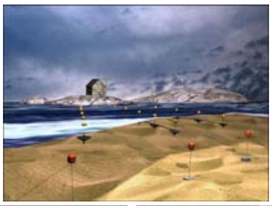
- Chapdrive AS ble etablert i 2006 og har utviklet og patentert et reguleringssystem for hydraulisk kraftoverføring i vindturbiner. Selskapets teknologi er basert på fremragende forskning ved NTNU-miljøet i Trondheim.
- ChapDrive har kontorer og verkstedlokaler på Marienborg i Trondheim.
- Selskapet eies av gründerne, Northzone Ventures, Hafslund Venture, StatoilHydro og NTNU Technology Transfer.
- Selskapet har i dag 10 ansatte og tilknyttede konsulenter. Selskapet har knyttet til seg eksperter fra internasjonal vindkraftindustri.
- ***VI HAR BEHOV FOR FLERE ANSATTE***
  Faglærte innen elektro, automasjon og mekanikk
  Sivil ingeniører inne elektro, hydraulikk og maskinteknikk

Spørsmål?

Takk for oppmerksomheten!

Anvendelser

- Tidevannsturbiner
- Onshore vind turbiner
- Offshore vind turbiner
- Bølgekraftverk
- Kombinasjon av tidevann, bølger og vind



1

Flytende vindturbiner

Modellering- og regulering

Thomas Fuglseth
Ph.D.-student, Inst. for Elkraftteknikk, NTNU

NTNU
www.ntnu.no

2

Flytende vindkraft – en industri for Norge?

- Norge har mye offshorekompetanse og en sterk energinæring
- Flytende vindkraft er av stor interesse internasjonalt
  - Stort marked i fremtiden
- Norske selskaper allerede inne på utviklingssiden
  - StatoilHydro (tidl. Hydro Energy)
  - Sway


1

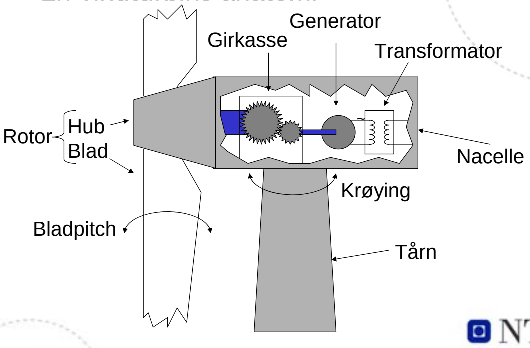

2

1) Sway AS
2) StatoilHydro

NTNU
www.ntnu.no

3

En vindturbins anatomi

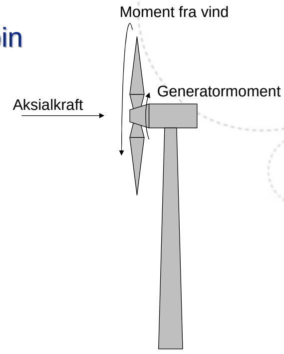


NTNU
www.ntnu.no

4

Krefter på en vindturbin

- To kraftkomponenter på bladet
  - Rotasjonsretning
  - Aksialretning
- Kraft i rotasjonsretningen skaper moment som driver generatoren
  - Gir oss energi
- Kraft i aksialretning bøyer bladene og tårnet
  - Gir oss bare slitasje

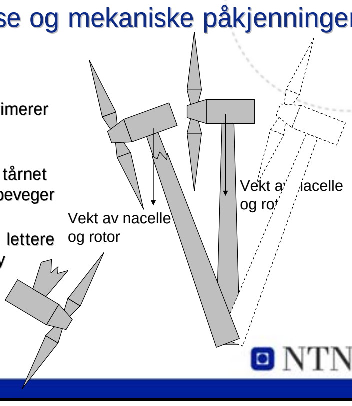


NTNU
www.ntnu.no

5

Størrelse, masse og mekaniske påkjenninger

- Landbasert turbin: nacellevekten komprimerer tårnet
- Flytende turbin: Nacellevekten bøyer tårnet når konstruksjonen beveger seg
- Krever sterkere tårn, lettere nacelle og/eller fancy regulering



NTNU
www.ntnu.no

6

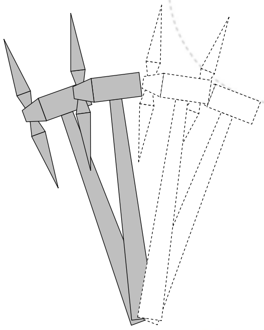
Hva kan vi styre?

- Bladpitch
  - Felles
  - Individuell
- Generatormoment og -turtall
  - Kun omformermatede generatorer
    - Dobbeltmatet asynkronmaskin (±30% turtall)
    - Asynkronmaskin med fullomformer
    - Synkronmaskin (viklet eller permanentmagnetisert rotor)

NTNU
www.ntnu.no

Felles bladpitch

- Bestemmer rotormoment
  - Turtall
  - Vindhastighet
- Bestemmer også aksialkraft
- Kan brukes til å dempe ut svingninger i tårn og plattform
  - Reduserer slitasje



NTNU

www.ntnu.no

Individuell bladpitch

- Kan dempe ut vibrasjoner i bladet
  - Varierende vindhastighet over rotordisken
  - 3P-effekten (tårnskygge)
- Kan forlenge levetiden på bladet eller tillate oss å bruke lettere bladkonstruksjon
- Men:
  - Mer slitasje på pitchmekanismen
  - Mer vridningsstress i bladroten

NTNU

www.ntnu.no

Generatormoment og -turtall

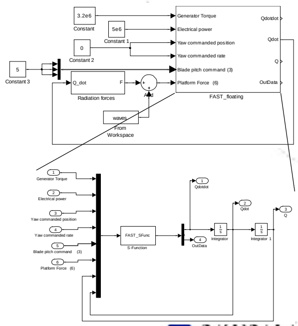
- Krever omformermatet generator
- Gir oss mulighet til å ta opp momentvariasjoner fra rotoren
  - Reduserer belastning på aksling og evt. girkasse
  - Kan gå ut over jevn kraftproduksjon
    - Er dette et problem?
    - Store parker jevner ut produksjonen

NTNU

www.ntnu.no

Hva driver jeg med?

- Modellere vindturbin og tårn med FAST
  - Freeware fra NREL
- Modellere plattform i WAMIT
  - Frekvensavhengig added mass og potential damping
- Linearisere WAMIT-data og representere frekvensavhengige størrelser som tilstandsrommodeller
  - Matlab / Simulink

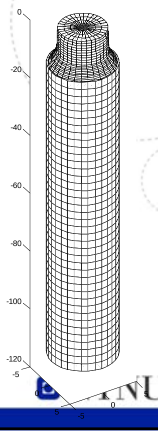


NTNU

www.ntnu.no

Wamitmodell

- Panelmetode
  - Strukturen deles opp i paneler
  - Trykk-krefter regnes ut ved numerisk integrasjon over alle panelene
- Geometridata generert med Matlab
  - Kan også bruke dedikert 3D-modellerings-programvare
- Wamit gir oss:
  - Frekvensavhengig added mass og potensialdemping
  - Responsfunksjoner for bølgepåvirkning



NTNU

www.ntnu.no

Strålingskrefter på tilstandsromform

Bevegelsesligning:

$$\sum_{k=1}^{6}(m_{jk}+\alpha_{jk}(\omega))\ddot{q}_k+\sum_{k=1}^{6}\beta_{jk}(\omega)\dot{q}_k+\sum_{k=1}^{6}c_{jk}q_k=\tau_j^D+\tau_j^A+\tau_j^E$$

Frekvensavhengig added mass og potensialdemping

$$\sum_{k=1}^{6}(m_{jk}+a_{jk})\ddot{q}_k+\sum_{k=1}^{6}b_{jk}\dot{q}_k+\sum_{k=1}^{6}c_{jk}q_k+\sum_{k=1}^{6}\underbrace{\int_{-\infty}^{t}K_{jk}(t-\sigma)\dot{q}_k(\sigma)d\sigma}_{\mu_{jk}}=\tau_j^D+\tau_j^A+\tau_j^E$$

Konstant added mass og potensialdemping

Frekvensavhengige termer som konvolusjonsintegral

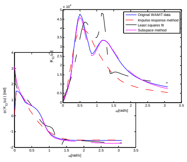
NTNU

www.ntnu.no

Strålingskrefter

- Finn $K_{jk}(\omega)$ fra WAMIT-simuleringer
- Bruk systemidentifikasjons-teknikker til å finne en tilstandsrommodell
  - Subspace-metoder har vist seg å gi best resultat
  - Verktøy: "n4sid"-funksjonen i Matlab System Identification Toolbox

$$\dot{\xi}_{jk} = \mathbf{A}_{jk}\xi_{jk} + \mathbf{B}_{jk}\dot{q}_k$$
$$\mu_{jk} = \mathbf{C}_{jk}\xi_{jk} + \mathrm{D}_{jk}\dot{q}_k$$



Bølgekrefter

Del valgt bølgespektrum inn i diskrete intervaller (~500)

$$\eta_i^2 = 2 \cdot S(\omega_i) \cdot \Delta\omega_i$$

i-ende komponent av bølge-amplitude

Bølgespektrum

Frekvensintervall

Vi antar sinusformede bølger

$$\eta_i(t) = \eta_i \cdot \sin(\omega_i t + k_i x + \varphi_i(t))$$

Romlig forskyving (vanligvis 0)

Tilfeldig fasevinkel

Bølgekrefter (2)

$$\eta(t) = \sum_i \sqrt{2 \cdot S(\omega_i) \cdot \Delta\omega_i} \cdot \eta_i(t)$$

Bølgeamplitude som funksjon av tid

$$F_{ex}(\omega) = H(\omega) \cdot \eta(\omega)$$

Bølgeinduserte krefter

$$F_{ex}(t) = H(t) * \eta(t)$$

Konvolusjonen kan løses numerisk, enten som et løpende integral i simuleringen eller det kan beregnes i forkant. Den siste metoden gir oss en pregenerert tidsserie av bølgekrefter heller enn bølgeamplitude.

Regulatordesign

- Ønsker å prøve ut mp-QP-basert regulering
  - Baserer seg på sanntidsløsning av et kvadratisk optimaliseringsproblem
  - Kan legge på variable begrensninger
  - Kan designes basert på systemmodell
    - Nært beslektet med Lyapunovteori
  - Egnet til regulering av ulineære systemer

"Vanlig" QP-optimalisering

- Minimer en kvadratisk kostfunksjon:

$$V(x) = \min_x \tfrac{1}{2} x^{\mathrm{T}} Q x + x^{\mathrm{T}} f$$

- Gitt følgende begrensninger:

$$g_i^{\mathrm{T}} x = w_i, \quad i \in \varepsilon$$
$$g_i^{\mathrm{T}} x \le w_i, \quad i \in I$$

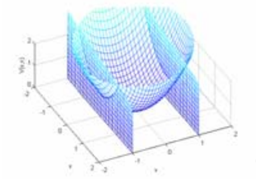
Multiparametrisk QP (mp-QP)

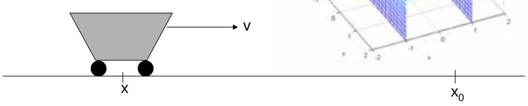
- Kvadratisk problem hvor problemformuleringen og begrensingene forandrer seg som funksjon av et sett med ekstern parametre u(t)

$$V(x) = \min_x x^{\mathrm{T}} Q x + x^{\mathrm{T}} F u(t)$$
$$\text{s.t. } Gx \le W + Su(t)$$

19

Eksempel





$$V(x) = \min_v \frac{1}{2}Mv^2 + \frac{1}{2}Q(x-x_0)^2$$

$$\text{s.t. } |v| \le W$$

NTNU

www.ntnu.no

20

mp-QP i reguleringssystemer

- QP-løsere (og LP) egner seg generelt ikke til bruk i sanntidssystemer
  - Ingen hard grense på hvor lang tid det tar å finne en løsning
- Regulering basert på optimalisering og tilstandsestimering har vært brukt i tregere prosesser
- Hva gjør vi?
  - Definer og løs problemet på forhånd
  - Del løsningsrommet opp i et søkbart sett med lineære funksjoner

NTNU

www.ntnu.no

21

Hvordan regulere?

- Bruk kjent fartøystyringsteori, og tenk på rotoren og generatoren som en aktuator
- Reguler for å redusere belastning
- Nedprioriter jevn effekt
  - Virkningen av større parker jevner ut den totale produksjonen

NTNU

www.ntnu.no

22

Kostnadsfunksjon

- Minimer en kvadratisk funksjon av følgende variable:
  - Plattformpitch
  - Bladutslag (flapwise og edgewise)
  - Forskjell mellom målt og ønsket moment
  - Forskjell mellom målt og ønsket fart
  - Vridning i aksling/girkasse

NTNU

www.ntnu.no

23

Begrensninger

- Harde begrensninger:
  - Maksimal rotasjonshastighet
  - Grenser for bladpitch
  - Maksimalt generatormoment
  - Maksimal mekanisk og elektrisk effekt
- Variable begrensninger:
  - Kommandert effekt (basert på målt vindhastighet)

NTNU

www.ntnu.no

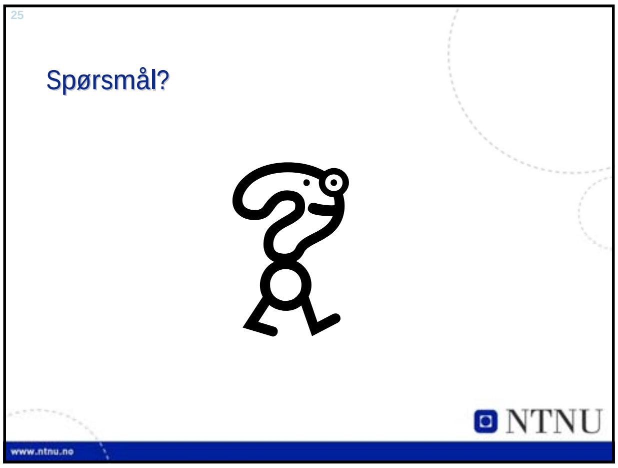
24

Avsluttende kommentarer

- Flytende offshore vindkraft har stort potensiale
  - Leverer mer energi enn tilsvarende turbiner på land
  - Unngår politiske problemer med vindkraft på land
- Krever nytenkning i forhold til eksisterende vindkraftteknologi for å bli lønnsom
  - Estetikk og støyegenskaper kan ofres for å gi bedre robusthet og økonomi
  - Regulering for levetid heller enn jevn produksjon
- Nytt bruksområde for norsk offshorekompetanse
- Nytt marked, vi kan være med fra starten

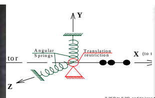
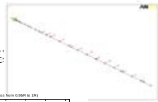
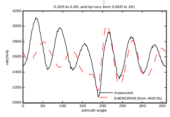
NTNU

www.ntnu.no


25
Spørsmål?
NTNU
www.ntnu.no

FEM Analysis of the NREL Phase VI Wind Turbine Blades

Haiyan Long, Simon-Philippe Breton and Geir Moe
Department of Civil and Transport Engineering, Norwegian University of Science and Technology, 7491 Trondheim, Norway

overview

- Background and Motivation
- Blade in NREL Tests
- FEM model
  - Elements & systems
  - Boundary
  - Damping
  - Loads
- Results in the downwind configuration
- Conclusion

Background & Motivation

- Downwind wind tubines might be possible in OWTs
  - Noise might be no longer an issure
  - Soft blades could be used
  - Centerfigure forces counteract the effect from aerodynamic forces
- Dynamics of downwind turbines due to tower shadows require further study.
- The measured data in NREL tests is expected to be reproduced by simulations .

Blades in NREL Tests

- Two-bladed 10.1-meter diameter wind turbine
- Blades of sections of S809 twisted and tapered
- The rotor was mounted with the blades in a fixed position relative to each other in the teetered configuration
- A 3.4 degree cone angle in the downwind cases is used

Fig.1 The Blades in NREL Tunnel

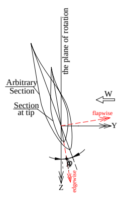


Fig.2 The blades sections

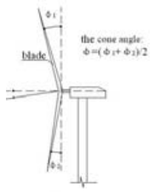


Fig.3 The blades flap angles

FEM model of the blades with Ansys

- Elements & Systems

Beam44 → Stiffness of the D spar

Mass21 → Mass of the blade

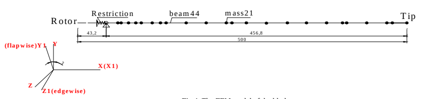
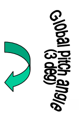


Fig.4 The FEM model of the blades

X-Y-Z → The system of the rotation

X1-Y1-Z1 → The flap-edgewise system



FEM model of the blades with Ansys

- Boundary condition
  - The model stops at 0,432m away from the rotational axis.
  - Rotations at root are allowable by means of the angular springs.
  - The stiffnesses of the springs are evaluated by equalizing the natural frequencies of the model to those determined experimentally

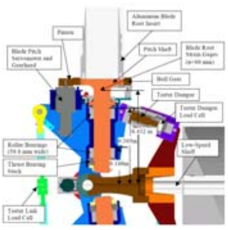


Fig.5 Rotor hub of the NREL turbines

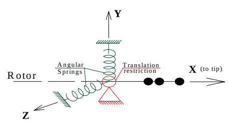


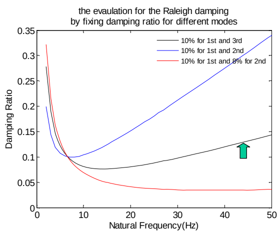
Fig.6 Boundary conditions in the FEM model

FEM model of the blades with Ansys

- Damping

Rayleigth damping

$$\xi_i = \frac{a_0}{2\omega_i} + \frac{a_1\omega_i}{2} \quad \text{Where:} \quad \begin{Bmatrix} a_0 \\ a_1 \end{Bmatrix} = 2\frac{\omega_m\omega_n}{\omega_n^2 - \omega_m^2}\begin{bmatrix} \omega_n & -\omega_m \\ -1/\omega_n & 1/\omega_m \end{bmatrix}\begin{Bmatrix} \xi_m \\ \xi_n \end{Bmatrix}$$



FEM model of the blades with Ansys

- Loads (gravity, centrifugal force and aerodynamic forces)
  - ✓ Gravity and Centrifugal forces

    They were simulated as *external force* to act on the model

    The value of these external forces in FEM model were evaluated by the principle of having contribution to the root moments as same as the gravity and centrigual force do on test
  - ✓ Aerodynamic forces (thrust and torque)

    Cubic spline interpolation from the measurements at 5 points (0.3R, 0.47R, 0.63R, 0.8R and 0.95R)

    Setting values at 25% equal to those at 30%

    A loss of lift at tip is considered: parabolic interpolation using measurements at 0.8R and 0.95R, and 0 force at tip

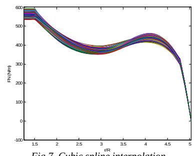


Fig.7 Cubic spline interpolation

Results (teetered configuration)

Downwind case: V=10m/s

Upwind case: V=10m/s

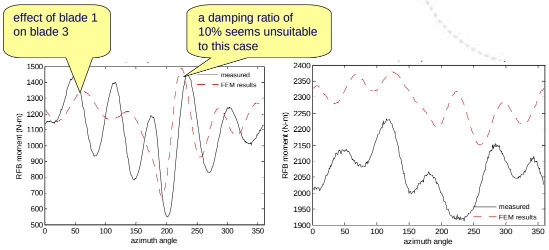


Fig.8 Comparison between the measurements and FEM results at the wind speed of 10m/s

Results (teetered configuration)

Downwind case: V= 20m/s

Upwind case: V= 20m/s

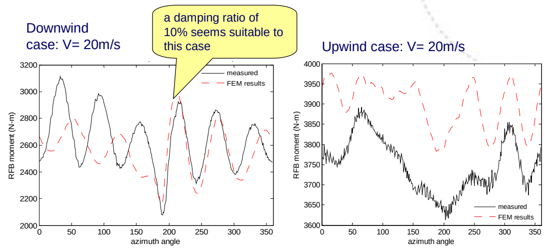


Fig.9 Comparison between the measurements and FEM results in the wind speed of 20m/s

Conclusion

- The 2D FEM model for the blades is an moderately efficient way to assess the root bending moments, at least in the region from 180 to 360, i.e. after passing the tower shadow and before the other blade reaches the tower shadow
- Damping varies with the experimental conditions,such as wind speed, cone, and configuration (upwind and downwind).
- Better simulation results could been obtained in downwind configuration if it was possible to changing the damping ratio azimuthally.

Simulering av flytende Offshore vindturbin

Andreas Knauer, Espen Hagen
IFE

Oversikt

- Introduksjon
- Numerisk modell
- Diskusjon av resultater
- Oppsummering og konklusjon

Turbine design

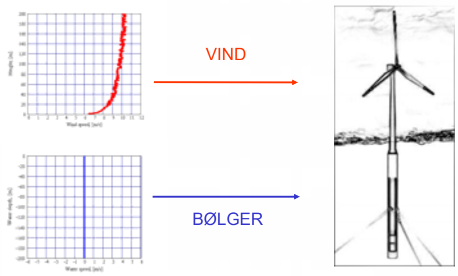
Designkondisjoner er forskjellig for offshore turbiner

Offshore (grunt vann):
- Lastbilde ligner onshore lastbilde
- Bølgeinduserte bevegelser er ikke dominante

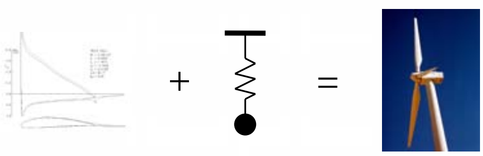
Offshore (deep-water):
- Komplekst, nytt lastbilde
- Bevegelser med 6 frihetsgrader
- Bølgeinduserte bevegelser
- Interaksjon bølger/turbin

Offshore laster

Det mer komplekse lastbildet for flytende konsepter krever nye, avanserte beregningsverktøy



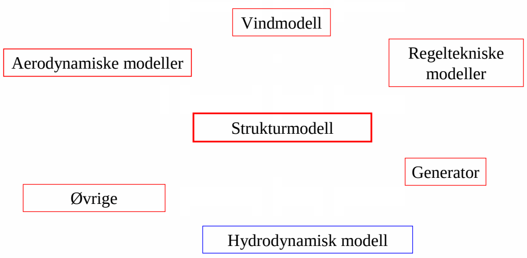
Aero - elastisk modell



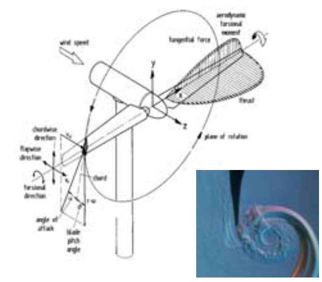
Flex 5 ble utviklet på DTU, Denmark. Dansk og tysk vindturbin-industri bruker Flex 5 som design-verktøy.

- Simulerer operasjon av vindturbiner med 1 til 3 blader, fast eller variabel rotorhastighet for pitch- eller stall kontroll.
- Simulerer defleksjonsmoder (1. og 2.) av vindturbinstrukturen fra fundamentet til bladspissen.
- Beregninger i tidsplan eller frekvensplan.
- Simulering av transienter som start/stopp pga. pitching eller 'braking'.

Flex 5 struktur



Aerodynamikk av rotoren



3D-Effekter

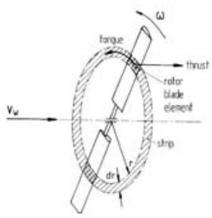
Blad tipp:

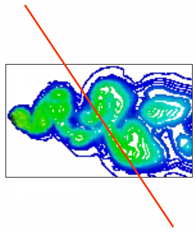
- 'Tip vortices'

Indre seksjoner:

- Løft amplifikasjon
- 'Stall delay'

Grenser for bladelementmetoden





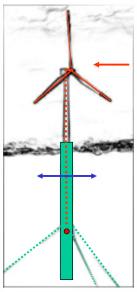
Offshore turbinmodeller

To strategier for simulering av flytende konsepter:

- Integrerte modeller
- Koblede modeller

Integrert IFE- modell:

Flex 5 pluss enkelt sub-modul for marin hydrodynamikk av en spar-buoy (HyWind-konsept).



Offshore floater

Hydrodynamisk sub-modul:

- Lineær bølgeteori for infinit vanndybde:

$$\phi = \sum_{i=1}^{n} \frac{g \cdot \zeta_{ai}}{\omega_i} \cdot e^{k_i z} \cos(\omega_i t - k_i x)$$

- Irregulære bølger er modellert med Pierson-Moskowitz bølgespektrum.
- Hydrodynamiske krefter og resulterende momenter er estimert med en enkelt drag modell:

$$F_i = \sum_{j=1}^{n} \frac{1}{2} \cdot \rho_{water} \cdot v_{ij\,rel}^{2} \cdot A_{ij} \cdot C_D$$

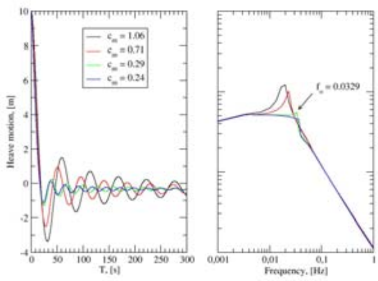
$$M_i = \sum_{j=1}^{n} \frac{1}{2} \cdot \rho_{water} \cdot v_{ij\,rel}^{2} \cdot A_i \cdot C_D \cdot (z_{COG} - z_{ij})$$

- Lineariseringer: konstante drag koeffisienter ble brukt. Dette tar ikke med Reynoldstall-, overflate- og hvirveleffekter. 'Added mass' er videre konstant.

Turbinmodell

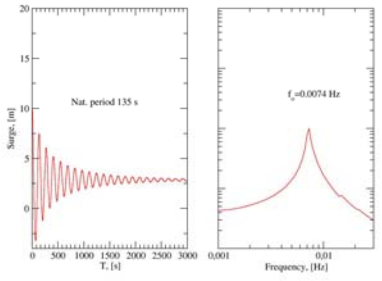
Turbine type:	pitch-regulated, variable-speed
Turbine power:	5 MW
Rated wind speed:	11.5 m/s
Blades:	3
Blade length:	61.5 m
Blade mass:	18200 kg
Hub height:	80 m
Tower mass:	300 tons
Turbine mass:	188 tons

Dynamiske egenskaper



Test: 0.0322 Hz

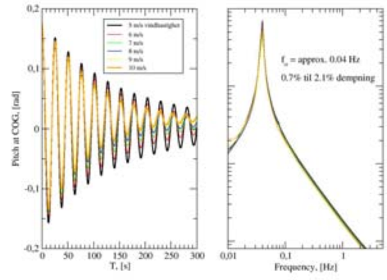
Dynamiske egenskaper



Test: 0.0823 Hz

2008-02-04

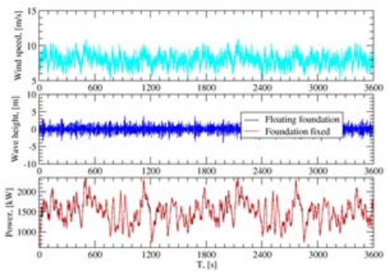
Dynamiske egenskaper



Test: 0.033 Hz

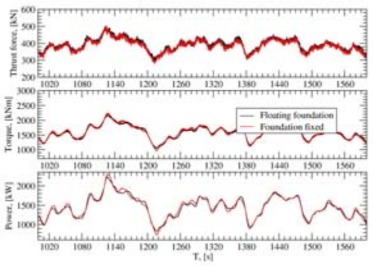
2008-02-04

Operasjon ved 8 m/s vind



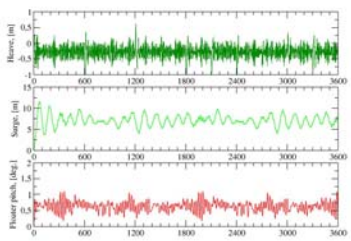
2008-02-04

Operasjon ved 8 m/s vind



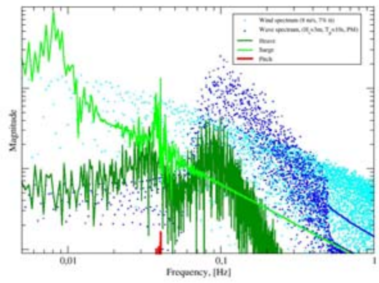
2008-02-04

Operasjon ved 8 m/s vind



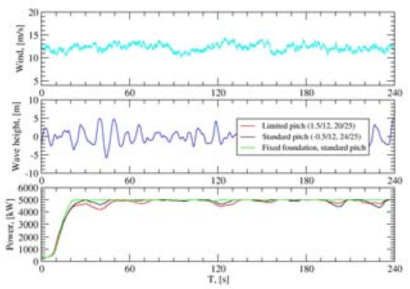
2008-02-04

Operasjon ved 8 m/s vind



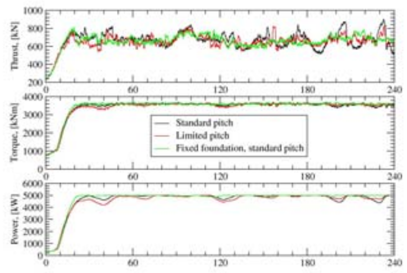
2008-02-04

Operasjon ved maks. thrust ved 12 m/s



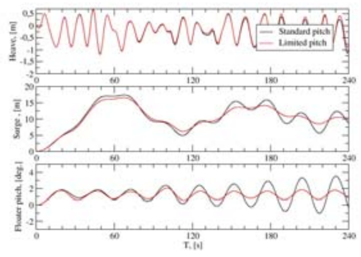
2008-02-04

Operasjon ved maks. thrust ved 12 m/s



2008-02-04

Operasjon ved maks. thrust ved 12 m/s



2008-02-04

Resultater

Numeriske egenskaper:

- modellen er stabil, også for maksimal thrust
- simuleringer er raske, omtrent 'realtime'

Første tester:

- Resultater for dynamiske egenskaper er ok
- Designtrender kan raskt bli estimert
- Identifikasjon av thrust-peaks for standard bladkontroll
- Eksitasjon av pitch-bevegelser
- I en test med begrenset blad pitch ble thrust-belastning dempet

2008-02-04

Oppsummering og konklusjon

En hydrodynamisk submodul ble integrert i den aero-elastiske modellen Flex 5. For simulering av bølger ble lineær bølgeteori brukt for infinit vanndybde. Irregulære bølger genereres med Pierson-Moskowitz spektrum og hydrodynamiske laster beregnes med en dragmodell.

I simuleringer av en 5 MW turbin på en 'floater' viste modellen numerisk stabilitet og effektivitet, også for høyere vindhastigheter. Resultatene viser et interessant potensial for modellen for kvalitative analyser. Estimering av potensialet for kvantitative analyser er i arbeid.

Konklusjon: Kombinasjonen av avansert aero-elastisk modell og et enkelt hydrodynamisk submodul virker og tilbyr mange muligheter for simuleringer, spesielt hvis den hydrodynamiske modellen utvikles.

2008-02-04

Driftssikkerhet for vindturbiner

Vindkraft FoU Seminar, Trondheim, 2008-01-24

Arnt Ove Eggen
SINTEF Energiforskning AS
Epost: Arnt.O.Eggen@sintef.no
Telefon: 73 59 64 82

NEtV-3 Driftssikkerhet for vindturbiner

- Prosjekteier — EBL Kompetanse AS, ved Lene Mostue / Henriette Rogde Haavik
- Utfører — SINTEF Energiforskning AS, ved Arnt Ove Eggen
  Samarbeidspartnere / Finansiører
  Samarbeid med KTH, Stockholm
  "Optimal underhållsstyrning av vindkraftverk med tillståndskontrollsystem med avseende på tillförlitlighet och kostnad"
- Varighet — 2006 – 2008
- Finansiering
  - EBL / kraftselskaper 2400 kkr
  - Elforsk 600 kkr
  - Norges forskningsråd 1000 kkr

Målsetning

Hovedmålsetningen med prosjektet er å utarbeide en kostnadseffektiv vedlikeholdssystematikk for vindkraftanlegg, samt å etablere et grunnlag for å gjøre riktige valg med hensyn på driftssikkerhet, drift- og vedlikehold når nye vindparker skal spesifiseres.

Systematikken skal bl.a. bestå av praktisk rettede håndbøker, og implementeres i aktuelle FDV-system.

Systematikk og verktøy utarbeidet innen vannkraft skal tilpasses og benyttes der det har relevans.

Aktiviteter

1. Prosjektledelse
2. Etablere felles kodeplan for vindturbiner
3. Utarbeide håndbok for tilstandskontroll av vindturbiner
4. Etablere et opplegg for systematisk registrering og rapportering av driftshistorikk
5. Etablere levetidsmodeller for utvalgte komponenter
6. Utarbeide anbefalinger knyttet til kontraktinngåelse
7. Resultatspredning

2. Etablere felles kodeplan for vindturbiner

- Det er etablert et forslag til felles kodeplan for vindturbiner med utgangspunkt i EBL's kodeplan
  EBL-K 245-2007 "Kodifisering av vindturbiner i EBLs Kodeplan"
- En kodeplan gir en unik identifikasjon av alle systemer, komponenter og deler i en vindturbin
  - Forenkler søk/gjenfinning i et databasert anleggsregister
  - Tilordning av dokumentasjon, tegninger/skisser, bilder
  - Registrering av tilstandsinformasjon
  - Registrering av feil og mangler
  - Tilordning av vedlikeholdstiltak
  - Generell ressursoppfølging
- En felles kodeplan for bransjen forenkler utveksling/innsamling av informasjon i forbindelse med benchmarking, utarbeidelse av nasjonale statistikker, estimering av ulike parametre, osv

3. Utarbeide håndbok for tilstandskontroll av vindturbiner

Aktiviteten deles inn i 4 delaktiviteter

1. Utarbeide komponentbeskrivelser med utgangspunkt i komponenter for en generisk vindturbin
2. Kartlegge og beskrive skademekanismer og feilårsaker
3. Kartlegge og beskrive aktuelle målemetoder inkl utarbeide tilstandskontrollskjema
4. Etablere anbefalte måleprogram, inkl flytdiagram som beslutningsstøtte ved endringer av måleprogrammet

Skadetyper

- Kort beskrivelse av de vanligste skadetypene for de enkelte komponentene i en vindturbin (tannhjul: micropitting, pitting, avskalling, scuffing, inntrykningsmerker, stillstandsmerker, klakking)

Tabell 5.1 Gir – skader på tannhjul

Årsaker	- Urenheter i oljen - Mekanisk slitasje - Utmatting - Deformasjoner
Mulige konsekvenser	- Sprekkdannelser i tenner - Avskalling på tenner - Tannbrudd - Lagerhavari
Prøvemetoder for påvisning [Utsagnskraft]	- Maskinovervåking [C] - Visuell inspeksjon, evt med endoskop [A] - Analyse av giroljen [B], [C] - NDT-kontroll [A]
Påvisning	- Vibrasjoner, temperaturøkning - Synlig tegn på skade - Partikkelinnhold i olje

Målemetoder

- Beskrivelse av de ulike målemetodene som kan benyttes for overvåking og diagnostisering av en vindturbins tilstand. Begrepet målemetode benyttes både for inspeksjoner og direkte målinger.
- Kriterier for karaktersetting av skader som kan observeres med de enkelte målemetodene
- Skadeatlas (bilder som illustrerer ulike skadeomfang)

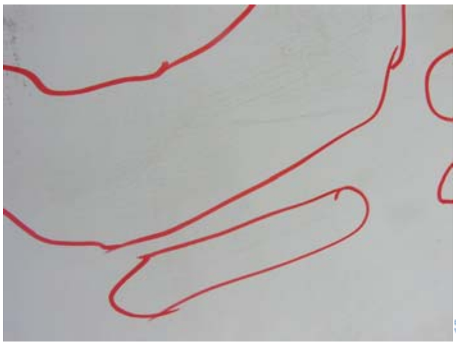
Tabell 5.6 Gir – Visuell inspeksjon

Karakter	Kriterier for karaktersetting
1	Micropitting på inntil 10 % av flankearealet.
2	Micropitting på mer enn 10 % av flankearealet.
3	Begynnende pitting.
4	Utbredt pitting eller avskalling.

Kriterier for karaktersetting

Karakter	Betydning
1	Ingen tegn til svekkelse
2	Noe tegn til nedbrytning Resultatet er noe dårligere enn i ny tilstand
3	Utbredt tegn til nedbrytning Betydelig dårligere enn i ny tilstand
4	Tilstanden er kritisk
5	Feil

Krakkelering av topcoat på blad



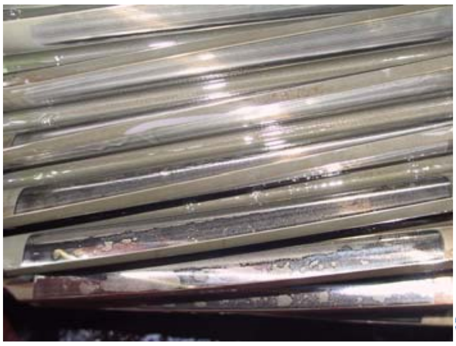
Hull i topcoat i forkant av blad

Sprekker nær bladrot

Lynskade ved lynreseptor

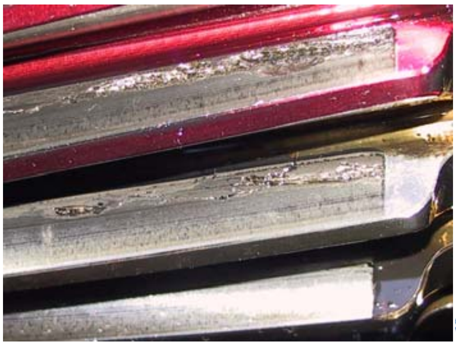
SINTEF | SINTEF Energiforskning AS | Arnt Ove Eggen 2008-01-24 13

Micropitting i gir



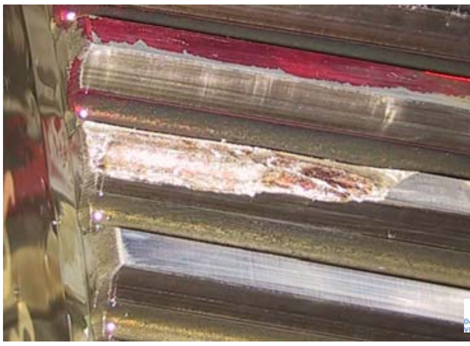
SINTEF | SINTEF Energiforskning AS | Arnt Ove Eggen 2008-01-24 14

Pitting og avskalling i gir



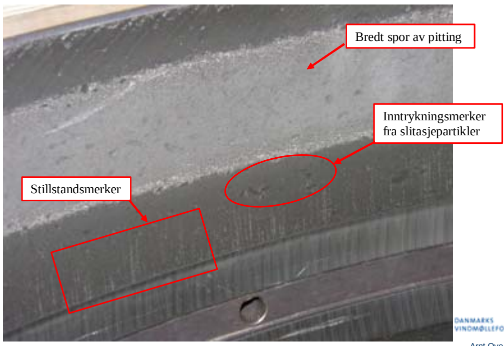
SINTEF | SINTEF Energiforskning AS | Arnt Ove Eggen 2008-01-24 15

Brukket tann i gir



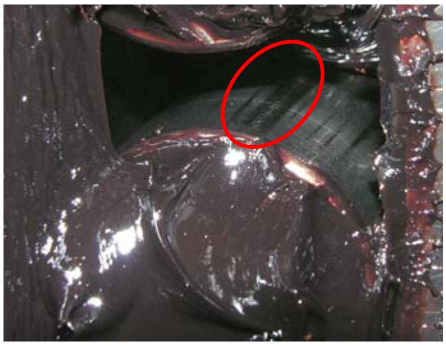
SINTEF | SINTEF Energiforskning AS | Arnt Ove Eggen 2008-01-24 16

Slitasjeskader i lager



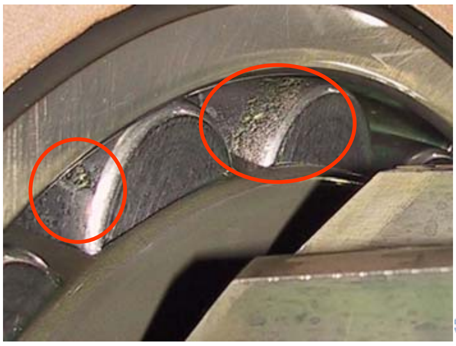
SINTEF | SINTEF Energiforskning AS | Arnt Ove Eggen 2008-01-24 17

Stillstandsmerker og pitting på ruller



SINTEF | SINTEF Energiforskning AS | Arnt Ove Eggen 2008-01-24 18

Pitting på ruller i lager



Pitting på innerring i lager

Måleprogram

- Gjennomføring av målingene er ofte både krevende og kostbar. Det er derfor viktig med en strategi for hvilke målinger som skal gjennomføres, og hvor ofte de bør utføres (måleintervall).
- Et standard måleprogram utføres med konstante tidsintervaller. Standard måleprogram representerer en minimumsløsning for vedlikeholdet. Dersom det inntreffer avvikende måleresultater vil det være aktuelt å iverksette tilleggsmålinger for å kunne bestemme tilstanden nærmere.

Tabell 5.8 Gir – Måleprogram

Tidsintervall	Måling	Vindturbinen stanses ved måling	Demontasje nødvendig
1 år	Visuell inspeksjon, oljeanalyse		
1 år	Vibrasjonsmåling		
5 år	Oljeskift (i hht oljeprøve)	X	

Ved påvist endring i oljekvalitet, spesielt ved øket forurensning i oljen, bør inspeksjons- og analyseintervallene reduseres betydelig.
På større vindturbiner (>0,5MW) skiftes oljen kun på bakgrunn av analyseresultat.

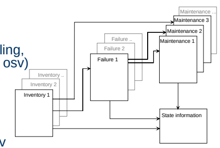
4. Etablere et opplegg for systematisk registrering og rapportering av driftshistorikk

Aktiviteten deles inn i 4 delaktiviteter

1. Kartlegge ytre driftspåkjenninger
2. Kodifisere feilbeskrivelser og feilårsaker
3. Spesifisere krav til dokumentasjon av driftserfaringer
4. Pilotaktivitet
   inkl samarbeid med leverandører av FDV-system

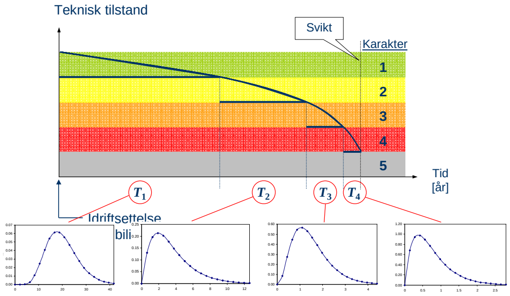
Datastruktur (basert på ISO 14224:2006)

- ***Utstyrsdata*** (*inventory*) beskriver utstyret som det samles data på
  - Fabrikat, typebetegnelse, modell, ytelse, osv
  - Idriftsettelsesdato
  - Navhøyde, rotordiameter, effektregulering, osv
  - Drifts- og miljøpåkjenninger (vindhastighetsfordeling, vindskjær, turbulensforhold, temperatur, nedbør, osv)
- ***Feildata*** (*failure*) beskriver svikt på utstyr
  - Tidspunkt for svikt, nedetid, osv
  - Feilmode, feilårsak, osv
  - Total driftstid, driftstid siden siste vedlikehold, osv



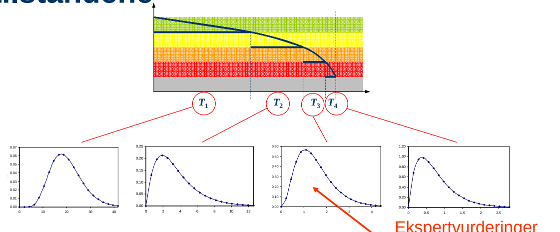
- ***Vedlikeholdsdata*** (*maintenance*) beskriver hvilket vedlikehold som blir utført
  - Forebyggende vedlikehold (tidsforbruk, reservedeler, kostnader, osv)
  - Korrigerende vedlikehold knyttet til hver enkelt svikt
- ***Tilstandsdata*** (*state information*) beskriver observert tilstandsutvikling, og er svært viktig for å kunne si noe om f.eks. P-F intervaller
  - Tidspunkt for måling, observert tilstand (Karakter 1, 2, 3, 4 eller målte parametre)
  - Data fra kontrollanlegget

5. Etablere levetidsmodeller for utvalgte komponenter



Kilde: Thomas Welte, NTNU

Forventet oppholdstid i de ulike tilstandene



Tabell 5.6 Gir – Visuell inspeksjon

Karakter	Kriterier for karaktersetting	E(T)	Var(T)
1	Micropitting på inntil 10 % av flankearealet.	?	?
2	Micropitting på mer enn 10 % av flankearealet.	?	?
3	Begynnende pitting.	?	?
4	Utbredt pitting eller avskalling.	?	?

6. Utarbeide anbefalinger knyttet til kontraktsinngåelse

- Det skal utarbeides anbefalinger for hvordan hensyn til fremtidig vedlikeholdsoppfølging skal ivaretas ved forhandlinger og ved kontraktsinngåelse
  - Innsyn til data i løpet av garantiperioden
  - Innsyn i informasjon om hendelser/feil/mangler/tiltak i løpet av garantiperioden
  - Innsyn i vurderinger og beslutninger som tas i løpet av garantiperioden
  - Rettigheter til å observere/lære av det leverandør gjør (kompetanseoverføring) i løpet av garantiperioden
  - Rettigheter til data som er samlet inn i løpet av garantiperioden
  - Garantitester ved utløp av garantiperioden

Oppsummering av forventede nytteverdier

- Felles kodeplan for vindturbiner
- Økt kunnskap om tilstandskontroll av vindkraftanlegg
- Økt kunnskap om hvordan drifts- og miljøpåkjenninger påvirker levetiden for vindkraftanlegg
- Systematisk registrering og rapportering av driftserfaringer
- Økt bestillerkompetanse
- Enhetlig terminologi slik at bransjen kan snakke "samme språk" rundt vedlikehold av vindkraftanlegg

Eksempler på større utskiftninger i offshore vindparker

- Horns Rev
  - Utskifting av gir og transformatorer, modifikasjon av pillarer
- Scroby Sands
  - Utskifting av lager i gir
- Nysted
  - Utskifting eller reparasjon av gir pga sprekker i tannhjul
- Middelgrunden
  - Utskifting av transformatorer pga overslag/kortslutninger pga sprekker

Off-shore vs on-shore vindturbiner

Sviktmekanismer

- Samme sviktmekanismer ?
- Noen mer fremtredende sviktmekanismer, f.eks. korrosjon ?
- Hurtigere utvikling på enkelte sviktmekanismer pga større mekaniske påkjenninger ?
- Høyere fokus på
  - materialvalg
  - konstruksjonsløsninger
  - kontinuerlig tilstandsovervåkning
  - nye drifts- og vedlikeholdsstrategier

Utfordringer

- Lavere "tilgjengelighet" for å utføre vedlikehold
  - større avstander
  - behov for båt
  - mer væravhengig
- Større logistikkutfordringer
  - båter, kraner
  - verktøy, reservedeler
- Vesentlig høyere vedlikeholdskostnader

Francois Besnard (PhD student, KTH)

- Title
  "Optimal maintenance management for offshore wind power systems using condition based monitoring systems with aspect to reliability and cost"
- Objective
  The aim of the project is to develop maintenance optimization models for windparks using condition monitoring residual life information, with a special focus on offshore conditions

Takk for oppmerksomheten !

Offshore vindkraft som nasjonal satsning – Energirådet

Paneldebatt

Tor-Odd Berntsen, Energirådet

Geir Moe, NTNU

Knut Mollestad, Statkraft

Kjartan Hauglum, Statnett

Petter Støa, SINTEF Energiforskning

Jonathan Mechineau, OWEC Tower

Energirådet

Møteplass for toppledere i energisektoren

Energirådet skal bidra til økonomisk og miljømessig verdiskapning i Norge og internasjonalt ved internasjonalisering av energisektoren gjennom samarbeid, kompetansebygging og teknologiutvikling

1

Energirådet

Møteplass for toppledere i energisektoren

- Energirådet er oppnevnt av og rapporterer til statsråden i OED, som også leder møtene (3 per år)
- Energirådet har 31 medlemmer
- Arbeidet i Energirådet ledes av et arbeidsutvalg
- Drøftinger i Energirådet

1. møte 14. juni 2007
Tema: Energisektoren – internasjonal næring eller nasjonal infrastruktur?

2. møte 12. november 2007
Tema: Vindkraft offshore som nasjonal utfordring

3. møte 25. februar 2008
Tema: Internasjonalisering av energisektoren

4. møte 5. mai 2008
Tema:

2

Utfordring til Energirådet

- Statsråden i OED har bedt Energirådet klarlegge den nasjonale verdien av en eventuell nasjonal satsning innen vindkraft offshore, og hva som skal til av samordning mellom aktørene for å kunne gjennomføre en slik nasjonal satsning
- Resultatet av arbeidet skal rapporteres i Energirådets møte 5. mai dette året
- Klarleggingen vil bli gjennomført som et samarbeid mellom en gruppe av medlemmer i Energirådet
- Energirådet inviterer til innspill i prosessen

3

Klarleggingen av den nasjonale verdien ved en eventuell satsning på vindkraft offshore

Det gjennomføres en økonomisk analyse , herunder industriutvikling, sysselsetting og tiltakskostnader som omfatter følgende:

- Scenarier for vindkraft offshore
  - Norsk/nordisk perspektiv
  - Europeisk perspektiv
- Etablering av regulatorisk rammeverk
- Utforming, dimensjonering og kostnadsestimering av kraftnettet offshore
- Utvikling av produksjonskostnaden for vindkraftanlegg offshore
- Miljø- og klimagevinster ved omlegging av kraftforsyningen
- Energi- og klimagevinster ved samkjøring av vind- og vannkraft
- Nødvendige rammevilkår og veien videre

4

Offshore vindkraft som nasjonal satsning - Energirådet

Paneldeltagere:

- Geir Moe, NTNU
- Petter Støa, SINTEF Energiforskning
- Kjartan Hauglum, Statnett
- Knut Mollestad, Statkraft
- Stig Svalheim, Lyse
- Eystein Borgen, SWAY
- Per Haugsøen, OWEC Tower

5

Eksempel - Ressursgrunnlag offshore vind

Område	Vanndyp	Potensial offshore [TWh] Enova estimat Utenfor 20 km	NVE-estimat, Kystnært	Total
Sum	0 – 30 m	11	114	125
	30 – 60 m	786	85	871
	60 – 300 m	12 970	n.d.	12 970
	Total	13 767	199	13 970

Potensialet for områdene mer enn 20 km fra kysten er beregnet gjennom å multiplisere arealet med 10 MW/(km)2 og en brukstid på 4000 timer (fullasttimer)

- Estimerte tall oppgitt:
  - Fordelt på tre klassifiseringer av vanndyp
  - Fordelt over geografiske områder langs kysten
  - Totale tall for Norge

Fremtidsbilde offshore vind

Eksempel på sammenstilling av informasjon i Enovas potensialstudie:

- Store prosjekter kreves for å bære kostnadene for infrastruktur.
- Trinnvis utbygging blir dermed vanskelig.
- Elektrifisering av sokkelen kan åpne for synergieffekter.
- Sør i Nordsjøen kan dette skje mellom 30 – 60 m dyp (gul farge på plott)

Supergrid concept

Research needed on:

Bottom-supported structures in up to 60(?) m waterdepth.

Much is known, but still an immature technology

Floaters: maybe soon – very likely in 30 years when oil and gas depletion and global warming increase the energy price level

As yet a totally immature technology

Research needed on **total concepts**: Designs to facilitate low fabrication costs, low maintenance costs, easy transportation and installation, - - - -

Research needed on specialized topics

Norsk vindkraft - fra tørt land til havblikk ?

Knut A. Mollestad, Trondheim 24. januar 2008

Statkraft REN ENERGI

Først en liten repetisjonsøvelse ……

Norsk vindkraft har snart 30-årsjubileum

- Forskningsprogram etablert ~1979
  - I regi av Institutt for Atomenergi (nå IFE)
- Vindforskningsstasjon etablert på Frøya i 1980
  - I regi av Fysisk institutt, NLHT (nå en del av NTNU)
- Første vindmølle satt i drift i 1986 på Frøya (55 kW)
  - I regi av Sør-Trøndelag Kraftselskap (nå TrønderEnergi)
- Første "vindmøllepark" på Vikna i 1992+1994 (tot. 2,2 MW)
  - I regi av Nord-Trøndelag E-verk (samme navn nå!)
- Første større vindparker satt i drift i 2002
  - Havøygavlen (Hydro) og Smøla (Statkraft) – begge 40 MW

Statkraft

side 2 23.01.2008

Dagens status på (og ved) land

- ca. 330 MW installert
- ca. 1.400 MW har konsesjon fra NVE
  - Men nesten halvparten er påklaget til OED
- ca. 5.400 MW er konsesjonssøkt
  - Hvorav 1500 MW "near-shore" (Havsul)
- Ytterligere ca. 85 prosjekter er "meldt" til NVE

………………………… ?

Statkraft

side 3 23.01.2008

Hva har preget de siste 5 – 6 årene?

- Lang myndighetsbehandling
  - Kronglete og med mange nye påfunn underveis
- Manglende politisk tydelighet
  - Festtaler uten innhold
- For dårlige rammevilkår
  - På tross av (meget) fagre løfter

Statkraft

side 4 23.01.2008

Offshore vindkraft i Norge

- Hva preger medieomtalen?
  - Ufattelig potensial
  - Flytende konstruksjoner
  - Enorme muligheter for Norge
    - Norsk industri vil bli verdensledende
  - Månelanding
  - Stor politisk interesse og støtte
    - Løfter om store forskningsprogrammer
  - "Ute av syne – ute av sinn"
- **Vindkraft på land kan avlyses!**
  - Er dette et greit utsagn?

Statkraft

side 5 23.01.2008

Teknologisk fokus

- Forskning og industriutvikling i sentrum
  - Få andre momenter er trukket inn
- Hva med tidsperspektivet?
  - Første prototyp (+ prototyp nr. 2 ?)
  - Et lite pilotanlegg (3 – 6 vindturbiner?) + et litt større pilotanlegg (10 – 20 vindturbiner?)
  - Et "lite" ordinært anlegg (20 – 30 vindturbiner?)
  - Ordinære anlegg i "full" størrelse 500 – 1000 MW?
- **Når får vi et virkelig stort volum?**

Statkraft

side 6 23.01.2008

Andre problemstillinger?

- Hva med forholdet til andre interesser?
  - Annen næringsvirksomhet
  - Miljø
- Hva med lovverket?
  - NVE har styringa ut til grunnlinja
  - Ingen myndighet dekker områdene utenfor grunnlinja
- Kostnadsnivået
  - 2 – 3 ggr kostnadsnivået på land?
- Nettilknytning
  - Hvor og hvordan – og hvor mye koster det?

Statkraft

side 7 23.01.2008

Hva har vi lært på land ?

- Ting tar (lang) tid
- Intet problem er for lite til at det kan fokuseres på
- Motstanderne finner veien til banen – alltid
  - De vinner dessuten alltid kampen om media
- Politikerne trekker seg når de fagre løftene får en prislapp og skal innfris
  - **Det dukker alltid opp nye løsninger som er mer lovende og mindre konfliktfylte, men som dessverre har en lei tendens til å ligge litt lengre fram i tid**

Statkraft

side 8 23.01.2008

Hva må også til for å lykkes offshore?

- Lær av historien fra ”land-vind”
  - Ikke glem snubletrådene
- Oppretthold fokus også på videre vindkraftutbygging på land
  - Vil kunne bidra med betydelig ny fornybar el-produksjon relativt raskt
  - Vil vise at vindkraft er pålitelig
  - Vil sikre viktige erfaringer for kraftbransjen, industrien, forskningsmiljøene og for myndighetene
  - Vil kunne bidra til industriutvikling
  - Vil være en viktig brobygger fram mot realisering av store framtidige offshore-prosjekter
- Ikke selg skinnet før bjørnen er skutt
  - Eller ha i det minste en plan for hvordan bjørnen skal skytes …

Statkraft

side 9 23.01.2008

Offshore kraftnett

Sintef, 24. januar 2008
Kjartan Hauglum, Statnett

Statnetts ansvar og fagområder

- Statnett skal legge til rette for et velfungerende kraftmarked med høy leveringssikkerhet
- Eier, bygger og drifter sentralnettet
- System ansvar og balansering av kraftnettet
- Flaskehalshåndtering
- Langsiktig nettplanlegging og utvikling
- Utenlandskabler
- Teknologikompetanse på kraftlinjer, kabler og utstyr
- Teknologikonsulent for utbyggere

Statnetts forutsetninger i arbeidet med offshore kraftnett

- Linjer må bygges og/eller forsterkes i perioden frem til 2020:
  - Statnetts nettutviklingsplan gir løpende info på søkte og planlagte oppgraderinger i sentralnettet
  - Det vil vurderes om spesielle forsterkninger må komme i forbindelse med økende andel offshore kraft
- Antatte nye kabler, godkjente eller bygget pr 2020
  - Skagerrak 4
  - Nordlink
  - NorNed 2
  - UK kabel
  - Kobling til Supergrid

  → Ca 4 – 6000 MW ny kapasitet
- Systemansvarlig for offshore nett må utpekes

Øvrige forutsetninger

- Rammebetingelser som utløser vindkraftutbygging offshore
  - En del produksjon på grunne områder; Møre, Trøndelag og Nordland
  - Mye produksjon fra flytende vindkraftparker
  - Eventuelt produksjon fra flytende gasskraftverk med rensing
- Mulig pålegg om del- eller helelektrifisering av olje og gass installasjoner
  - 1000 – 1500 MW forbruk offshore
- Myndighetene etablerer spesifikke vindkraftområder
- Offshore vindparker knyttes til dedikerte nettpunkter
- Radialer eies og bekostes av vindkrafteier, bygges i samarbeid med regionalnetteier og Statnett
- VSC HVDC teknologien må videreutvikles
- Norsk offshore kraftnett knyttes til et internasjonalt "Supergrid"

Offshore kraftnett - skisse 2020

- Statnett har startet arbeidet med å utarbeide en skisse for et mulig offshore kraftnett
- Trinnvis utbygging er sannsynlig
- Prioritering av utbyggingsområder
- Prinsipper for tariffering offshore
- Investeringsanslag
- Mulige konsekvenser for onshore kraftnett beskrives

Radialutbygging, sannsynlig innledning

- Kystnære områder dekkes med AC
- DC benyttes for øvrige områder

Norsk vind og vannkraft passer godt i dette bildet

Kilde Airtricity

7

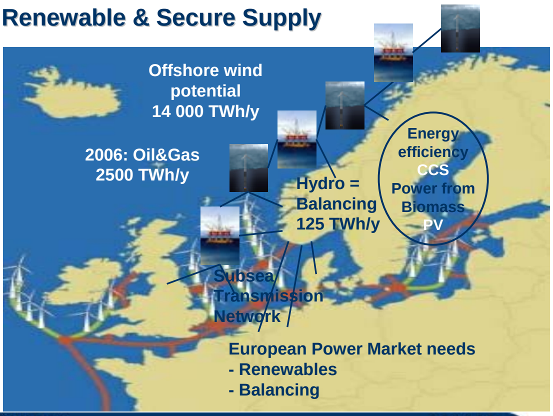
SINTEF

Technology for a better society

Vindkraft FOU Seminar
-fremtiden er offshore –

Petter Støa
Forskningssjef Energisystem

Renewable & Secure Supply



Drivere og muligheter for Norge

- Drivere
  - Klimautfordringen – mer fornybar energi
    - Norge
    - Europa
    - Globalt
  - Leveringssikkerhet Europa
    - "Vennlige" kilder
    - Balansekraft
- Muligheter
  - Fornybar eksportør
    - Offshore vind
  - Nordsjø subsea transmisjon
    - Utbygging
    - Drift
    - Leverandørindustri
  - Selge effektregulering
    - Europeisk Marked
    - Mer effekt
  - Fornybar industri
    - CCS
    - Biokraftvarmeverk

Kritiske suksessfaktorer

- Politikk for Norge
  - Fornybar eksportør?
  - Utvikle fornybar industri? Hvilken?
  - Et Europeisk Prosjekt – Norge må skape og velge roller
- FOU kompetanse
  - Senter for Offshore FOU
    - PhD skole (stipendiater, postdocs, professorer)
    - Forskere (faste, gjester)
  - Laboratorier: Nasjonalt "deep sea" laboratorium
  - Gode finansieringsmuligheter for demo/prototyper
- Industriell kompetanse
  - Energiselskap
  - Leverandør

OWEC Tower AS
OWEC Jacket Quattropod

OWEC Tower AS 1

OWEC Tower AS
Experience

- 30 years offshore oil and gas (fixed and floating, DnV etc.)
- Foundations for offshore wind since 2001

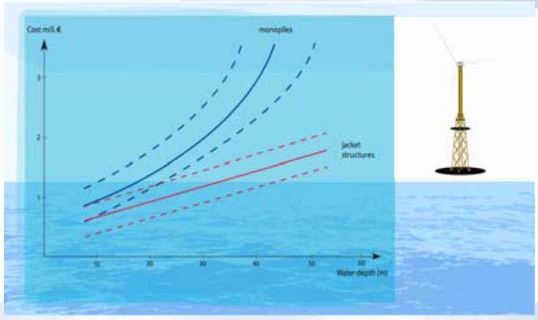
OWEC Tower AS

Partners

- Burtnisland Fabricators
  (www.bifab.uk.co)
- NorWind (EPCI)
  (www.norwind.no) (www.grieg.no) (www.scatec.no)

OWEC Tower AS 3

Jacket foundations vs monopiles:
Typical cost versus Water Depth



OWEC Tower AS 4

OWEC Tower –
continuous development

- Improvements on design;
- Mass fabrication;
- Installation technologies.

OWEC Tower AS 5

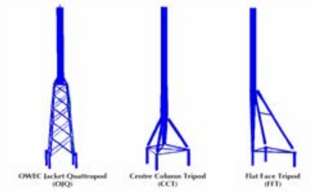
Beatrice
(DOWNVInD)

- European demonstrator project
- Managed by Talisman Energy and supported by SSE
- Supported by the European Union and British Authorities
- Licence agreement with OWEC Tower on foundation structure
- Total budget around 40 mill £

OWEC Tower AS 6

Selection of foundation/tower for the DOWNVInD (Beatrice) project

- Studies over two years; first two tripod concepts proposed;
- OWEC Jacket Quattropod was finally chosen.

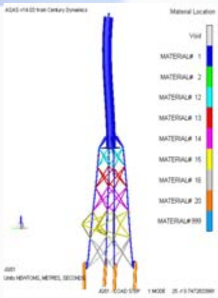


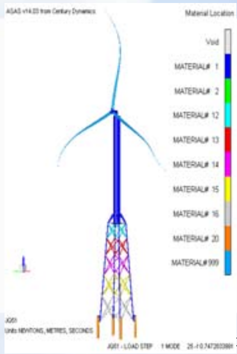
(Ref: Marc Seidel and Gunnar Foss)

Installering OJQ (2006)

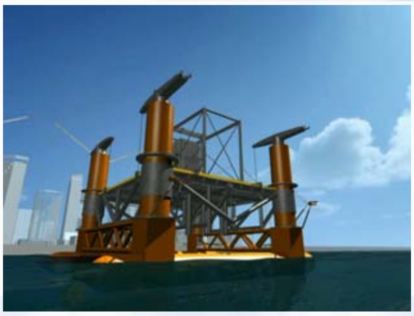
Beatrice and OWEC Jacket Quattropod (2007)

OWEC Jacket Quattropod –well verified

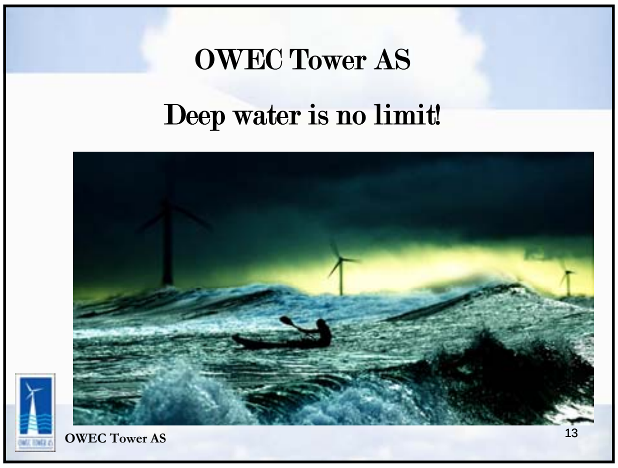




Installation- new methods must be considered to reduce cost



Norges Super grid – Super Power !


OWEC Tower AS
Deep water is no limit!
OWEC Tower AS
13

TradeWind – Transmission

Introduction, Session Chair: Frans Van Hulle, EWEA

The TradeWind power system simulation tool – modelling of the Nordel system, Seniorforsker Kjetil Uhlen, SINTEF Energiforskning

Wind and grid scenarios for Nordel – first simulation results,
Senior research scientist Bettina Lemström, VTT

Grid connection perspectives of Kriegers Flak, Senior Project Manager Göran Loman, Vattenfall AB

The European Wind Integration Study EWIS
Transmission planning in view of wind integration in NORDEL area,
Fredrik Norlund, SvenskaKraftnät

TradeWind

TradeWind Synchronous Zone Seminar 3
NORDEL

Frans Van Hulle (EWEA)

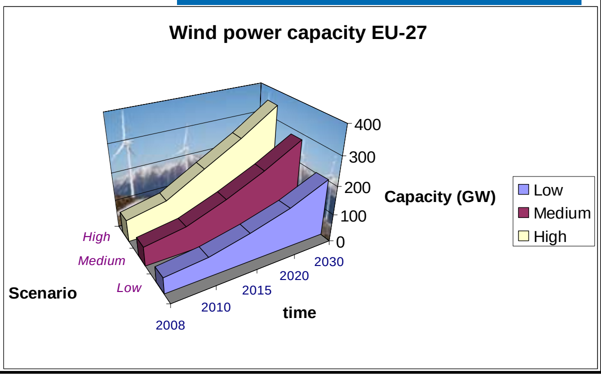
Trondheim, 25 January 2008 (Norway)

Backdrop

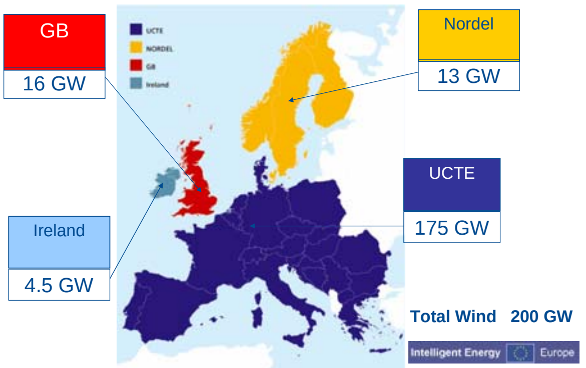
- Large amounts of new spatially uncorrelated variable output generation bring new challenges at a European scale:
  - Transmission network infrastructure is weakly interconnected
  - Power market design is not optimally suited for integration Inefficiency of cross border allocations and lack of flexibility in time
  - Desirable improvements go hand in hand with creation of single European electricity market
- The network and market aspects of large-scale wind power integration have not been studied before at a European level. EWIS and TradeWind are pioneering in this respect.

Intelligent Energy Europe

Estimated installed WP capacities (TradeWind)



Distribution of wind power capacity (2020)



Intelligent Energy Europe

Purpose of this seminar

INITIATIVE IN THE FRAMEWORK OF TRADEWIND

- Bring together the TradeWind team with stakeholders in NORDEL
- Inform about the project
- Get specific feedback from stakeholders in NORDEL zone
  - Validate and fine-tune the method / approach
  - Specific integration issues
  - Specific aspects for investigation

WHO HAS BEEN INVITED?

- Developers, TSO's (local and EWIS), Regulators, Consultants, engineering companies, electricity traders

Intelligent Energy Europe

How will we work today?

- Programme reflects the double focus of TradeWind: **transmission** and **power markets**
- Presentations by TradeWind, followed by presentations of invited parties on related topics
- Speakers please introduce yourselves
- Discussion is strongly encouraged:
- Power points will be available at the website of TradeWind
- Conclusions of the workshop will be reflected in the TradeWind reports and publications

Intelligent Energy Europe

ITINERARY TODAY

TRADEWIND (ASSUMPTIONS / TOOLS) 13:00 – 13:50
- Power system simulation tool – modelling of the NORDEL System (Kjetil Uhlen, SINTEF)
- Wind and grid scenarios for Nordel – first simulation results (Bettina Lemstrom, VTT)

TRANSMISSION (13:50 to 15:00)
- Grid connection perspectives of Kriegers Flak
- The European Wind Integration Study of TSO's – EWIS (Fredrik Norlund, Svenska Kraftnätt)
- Transmission planning in view of wind integration in the NORDEL area (Fredrik Norlund, Svenska Kraftnätt)

Break (15:00 to 15:20)

MARKET MECHANISMS (15:20 to 17:00)
- Market mechanisms facilitating efficient system operation with large amounts of wind power (Achim Woyte, 3E)
- Grid and market development within Nordel – balancing and trans-national transmission (Jan Braaten, Statnett)
- Development of wind farms in a market perspective (Erlend Broli, Statkraft)

DISCUSSION AND CONCLUSIONS (16:50 – 17:00)

Intelligent Energy Europe

Objective of TradeWind

"Wind power integration and exchange in the Trans-European Power Market"
- Recommend market rules and interconnector allocation methods to support wind power integration
- Propose solutions to facilitate maximum exchange of wind electricity via markets
- Target: TSO's, generators, regulators, market parties, authorities, TEN-E

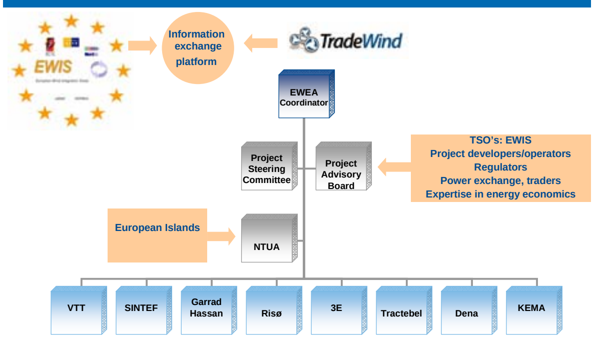
Intelligent Energy Europe

Project Facts

- **Financial support:** IEEA Intelligent Energy Europe (call of October 2005) contract nr EIE/06/022/SI2.442659
- **Running time**: 2 years (01/11/06 to 31/10/08)
- **HR effort**: 10 person years
- Co-operation with **EWIS** (European Wind Integration Study) of TSO's

Intelligent Energy Europe

TradeWind consortium



Intelligent Energy Europe

TradeWind and EWIS-Study

TradeWind
- Large wind power penetration
- Short to long term 2030
- Wind power scenarios and generation
- Equivalent grid model
- Transmission infrastructure and operation
- Market rules and organisation

EWIS
- Medium penetration
- Short/medium term 2008-2015
- Detailed power system study
- Maintain frequency and voltage stability, secure operation of grid / risk assessment
- Harmonised grid connection requirements
- Market models and procedures

Intelligent Energy Europe

TradeWind — Project Approach

Phase	WP	WP	WP
Phase 1 Preparation			
6 months	WP2 (GH) Wind power scenarios	WP3 (Sintef) Grid modelling and power system data	WP4 (Risoe) Identification of market rules
Phase 2 Simulation and analysis			
12 months	WP4 (VTT) Continental power flows	WP6 (Sintef) Grid scenario's	WP7 (3E) Analysis of market rules
Phase 3 Recommendations			
6 months	WP8 (EWEA) Recommendations for grid upgrade, market organisation and policy development		

Intelligent Energy Europe

TradeWind — Project Approach

Phase	WP	WP	WP
Phase 1 Preparation			
	WP2 (GH) Wind power scenarios	WP3 (Sintef) Grid modelling and power system data	WP4 (Risoe) Identification of market rules
Phase 2 Simulation and analysis			
12 months	WP4 (VTT) Continental power flows	WP6 (Sintef) Grid scenario's	WP7 (3E) Analysis of market rules
Phase 3 Recommendations			
6 months	WP8 (EWEA) Recommendations for grid upgrade, market organisation and policy development		

Intelligent Energy Europe

TradeWind — Ongoing work

WP5 (VTT)

Continental power flows

- 5.1 Moving weather effects
- 5.2 Transmission bottlenecks
- 5.3 Uncertainty analysis
- 5.3 Capacity credit of wind power

WP6 (Sintef)

Grid scenarios

- 6.1 Critical transmission corridors
- 6.2 Offshore grid scenarios
- 6.3 Grid upgrade measures
- 6.4 Ranking of measures

WP7 (3E)

Analysis of market rules

- 7.1 Significant interconnectors
- 7.2 Market barriers at significant interconnectors
- 7.3 Adapted market & allocation rules

Intelligent Energy Europe

TradeWind — Topics, messages and deliverables

- Quantified effects of distributed wind power feed-in on continental and cross-border flows. In time steps until 2030, including uncertainties resulting from forecast errors
- European capacity credit of wind power (boosted by interconnection)
- Ranked recommendations for offshore and onshore grid upgrade; by investigating different scenarios looking at selected transmission corridors
- Survey of power exchange market rules and constraints
- Proposals of solutions to facilitate maximum exchange of wind electricity via markets resulting from extensive market simulations

Intelligent Energy Europe

TradeWind

TradeWind Power System Simulation Tool
Grid modeling and power system data

Leif Warland, Magnus Korpås, John O. G. Tande,
Kjetil Uhlen

SINTEF Energy Research

3rd Synchronous Zone Seminar: Nordel,
Trondheim, 24.01.2008

Intelligent Energy Europe

TradeWind — Contents

- Objectives of the work
- Modelling approach
- Collected data
- Example simulation results
- Summary and further work

Intelligent Energy Europe

TradeWind — Objectives of the work

- Preparation of a European grid model
  - allowing simulation of cross border flows relevant for wind power integration studies.
- Simulation model based on existing market model with simplified grid representation
  - aggregated generation capacities and marginal costs of each generator type within each area of the grid.
- Collection of required data
  - load, generation and grid data

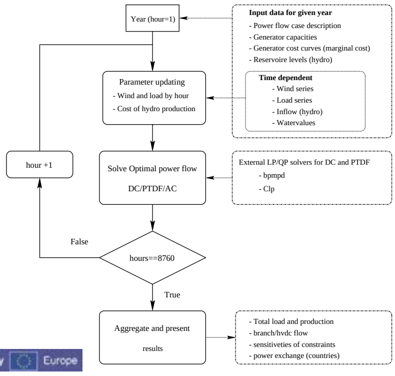
Intelligent Energy Europe

TradeWind — Power System Simulation Tool

- Main characteristics
  - Implemented in Matlab
  - Network models of UCTE, Nordel and UK (reduced)
  - Time series of load and wind for each country/grid zone
  - Installed/available generation capacities
    - Hydro, Nuclear, Fossil and renewables.
  - Marginal costs for each generator type
  - Reservoir levels, inflow and water values for Hydro plants
- Minimisation of total generating costs each hour of the year
  - assuming ideal market
  - power flow on lines given by PTDF representation
  - linear, piece-wise linear or quadratic cost functions

Intelligent Energy Europe

TradeWind — Simulation procedure



Intelligent Energy Europe

TradeWind — Network modelling

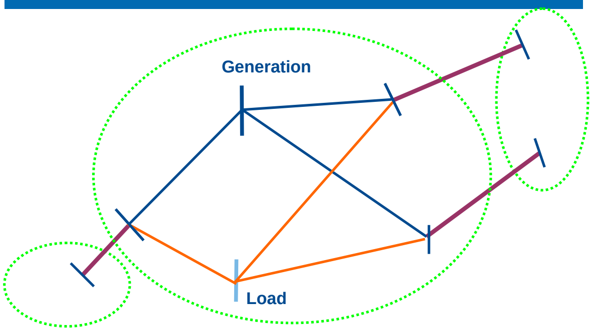
Grid representation UCTE

- Zonal approach:
- Modelling of individual lines or corridors between zones
- DC power flow, or
- PTDF-solution

K. Purchala, SUEZ Tractebel

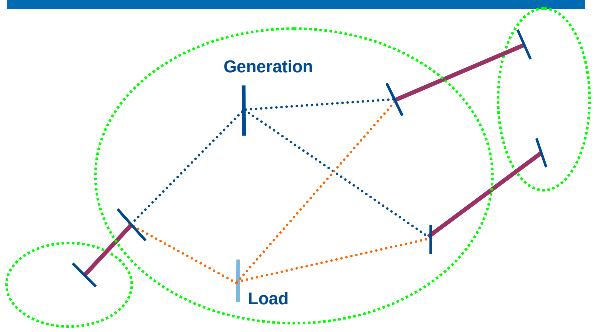
Intelligent Energy Europe

TradeWind — Network model DC



Intelligent Energy Europe

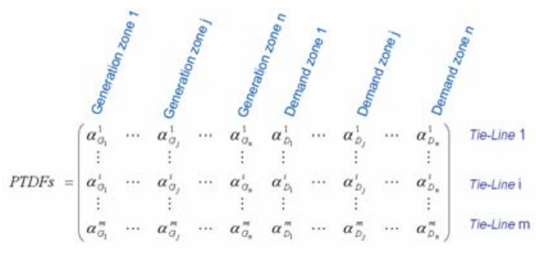
TradeWind — Network model PTDF



PTDF = Power Transmission Distribution Factor

Intelligent Energy Europe

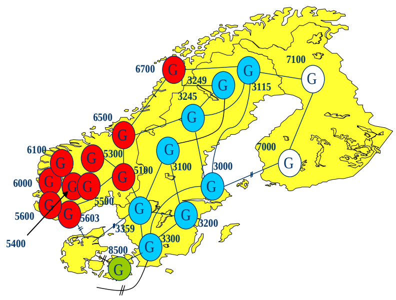
TradeWind — PTDF matrix



K. Purchala, SUEZ Tractebel

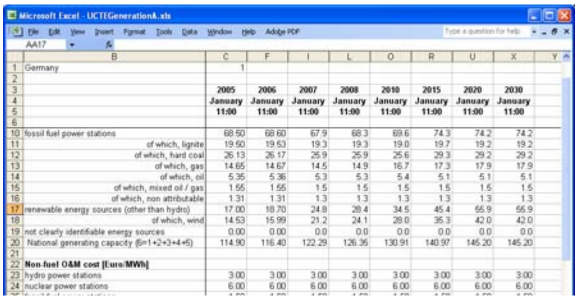
Intelligent Energy Europe

TradeWind — Grid representation – Nordel synchronous area



Intelligent Energy Europe

TradeWind — Input data example


Microsoft Excel - UCTEGenerationA.xls

	B	C	F	I	L	O	R	U	X
1	Germany	1							
3		2005	2006	2007	2008	2010	2015	2020	2030
4		January	January	January	January	January	January	January	January
5		11:00	11:00	11:00	11:00	11:00	11:00	11:00	11:00
10	fossil fuel power stations	68.50	68.60	67.9	68.3	69.6	74.3	74.2	74.2
11	of which, lignite	19.50	19.53	19.3	19.3	19.0	19.7	19.2	19.2
12	of which, hard coal	26.13	26.17	25.9	25.9	25.6	29.3	29.2	29.2
13	of which, gas	14.65	14.67	14.5	14.9	16.7	17.3	17.9	17.9
14	of which, oil	5.35	5.36	5.3	5.3	5.4	5.1	5.1	5.1
15	of which, mixed oil / gas	1.55	1.55	1.5	1.5	1.5	1.5	1.5	1.5
16	of which, non attributable	1.31	1.31	1.3	1.3	1.3	1.3	1.3	1.3
17	renewable energy sources (other than hydro)	17.00	18.70	24.8	28.4	34.5	45.4	55.9	55.9
18	of which, wind	14.53	15.99	21.2	24.1	28.0	35.3	42.0	42.0
19	not clearly identifiable energy sources	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
20	National generating capacity (6=1+2+3+4+5)	114.90	116.40	122.29	126.35	130.91	140.97	145.20	145.20
22	**Non-fuel O&M cost [Euro/MWh]**								
23	hydro power stations	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
24	nuclear power stations	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00

Intelligent Energy Europe

TradeWind — Generator cost data

	Non-fuel O&M cost [€/MWh]	Fuel efficiency [%]	Fuel cost [€/MWh]	Tax [€/MWh]	Marginal cost [€/MWh]
hydro power stations	3.0	100	0.0	0.00	3
nuclear power stations	6.0	100	5.0	0.00	11
fossil fuel power stations	1.5	49	12.6	0.00	27
of which, lignite	3.3	37	5.4	0.00	18
of which, hard coal	3.3	37	5.7	0.00	19
of which, gas	1.5	49	12.6	0.00	27
of which, oil	5.0	30	15.0	0.00	55
of which, mixed oil / gas	5.0	30	14.0	0.00	52
of which, non attributable	5.0	30	16.0	0.00	58
renewable energy sources (other than hydro)	4.0	49	14.0	0.00	33
of which, wind	2.0	100	0.0	0.00	2
not clearly identifiable energy sources	5.0	30	17.0	0.00	62

Intelligent Energy Europe

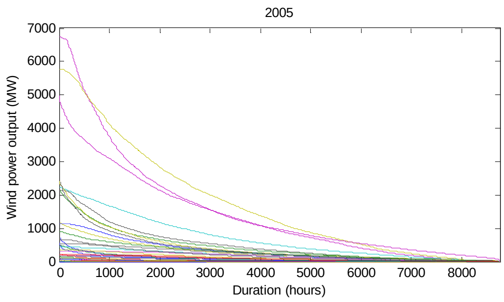
Wind data
WP2.4: Wind speed time series

- Re-analysis Data Points (RDPs) (2.5°, ΔX~180 km, ΔY ~280 km)

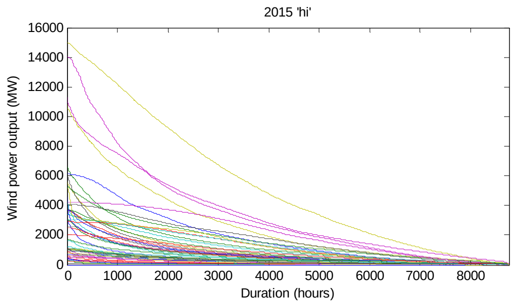
Wind data
Mapping wind data to grid model

Area	Zone	Region Identifier (Node)	RDP mapping	2005 Actual	2008 L	2008 M	2008 H
AT	A1	1	106	819	990	1015	1045
BE	BE	2	121	167	219	433	632
BE	BE	3	139	0	138	138	202
BG	BG	4	71	0	0	0	0
BG	BG	5	72	0	0	0	0
BG	BG	6	73	10	30	40	55
HR	HR	7	87	3	75	100	150

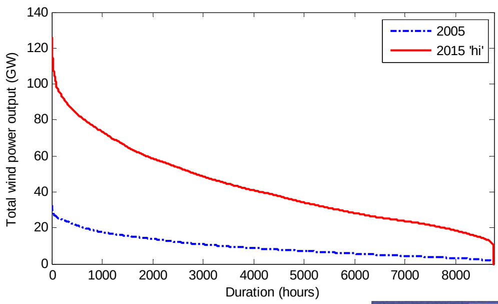
Wind power duration curves 2005



Wind power duration curves 2015 'hi' scenario



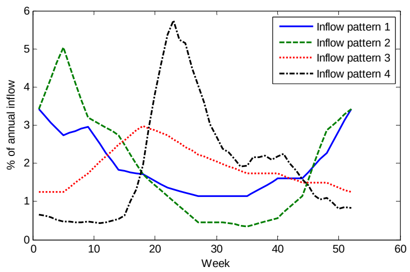
Wind power duration curves (totals)



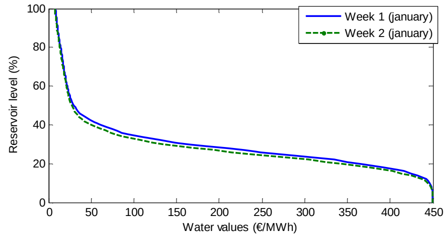
Hydro data

Country	Code	Capacity (GW)	Reservoir (TWh)	Inflow (TWh/yr)	Pumping capacity (GW)	Start reservoir (%)	Inflow pattern
Germany	DE	8,7	0,30	16,8	3,8	70	1
Belgium	BE	1,4	*0,03*	0	1,3	70	1
Luxemburg	LU	1,1	*0,03*	0	1,1	70	1
France	FR	25,5	9,80	55	4,3	70	3
Switzerland	CH	13,3	8,60	30,4	1,6	70	3
Italy	IT	21	7,90	35,5	4,2	70	3
Austria	AT	12	3,20	31,5	2,9	70	3
Spain	ES	18	18,40	24,8	3,3	70	2
Norway	NO	28	82,00	136	0	70	4
Sweden	SE	16	28,00	72,6	0	70	4
Czech	CZ	2,1	*0,54*	2,5	1,1	70	3
Slovenia	SI	0,9	0,00	3,1	0	70	3
Greece	GR	3	2,40	6	0,7	70	2

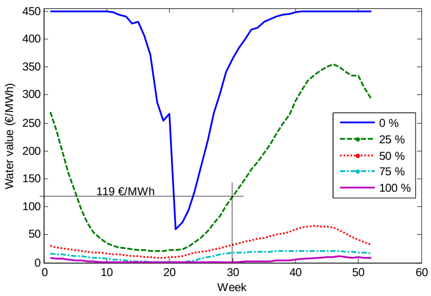
TradeWind — Inflow to hydro reservoirs



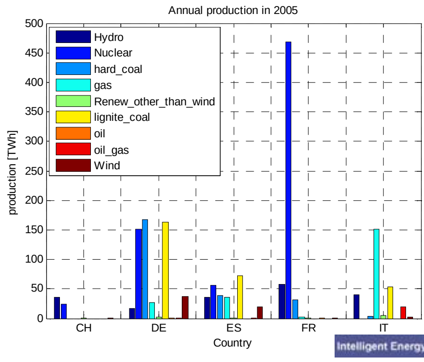
TradeWind — Marginal cost of hydro power



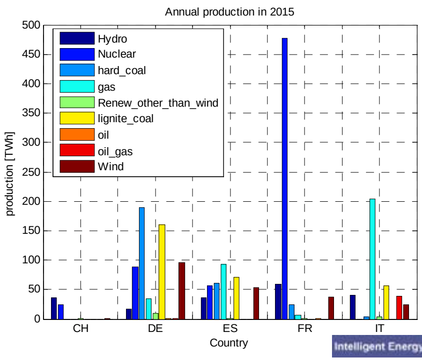
TradeWind — Marginal cost of hydro power



TradeWind — Example results 2005

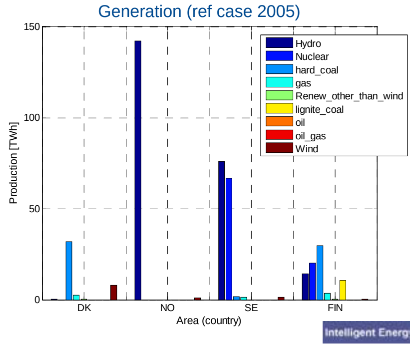


TradeWind — Example results 2015



TradeWind — Example results Impact of NorNed cable

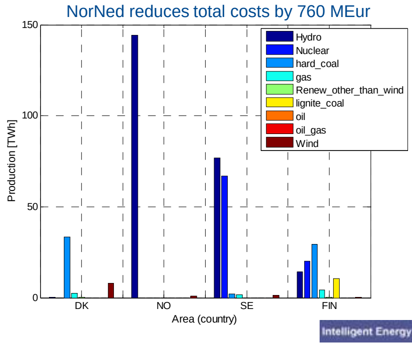
Generation (ref case 2005)



96

TradeWind — Example results: Impact of NorNed cable

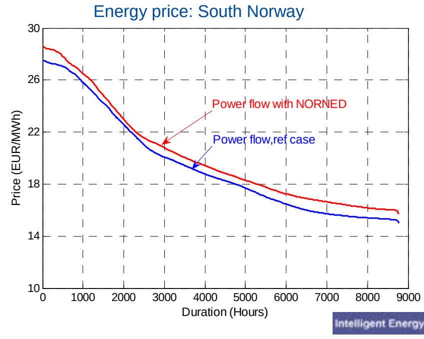
NorNed reduces total costs by 760 MEur



Intelligent Energy Europe

TradeWind — Example results: Impact of NorNed cable

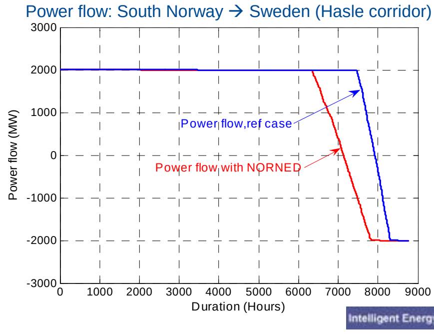
Energy price: South Norway



Intelligent Energy Europe

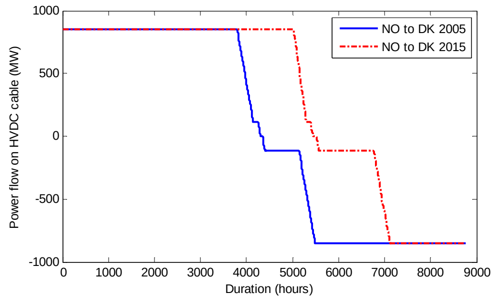
TradeWind — Example results: Impact of NorNed cable

Power flow: South Norway → Sweden (Hasle corridor)



Intelligent Energy Europe

TradeWind — Example results. HVDC flows



Intelligent Energy Europe

TradeWind — Summary

- The power system simulation tool is implemented
  - Choice of model is a trade-off between data requirements, accuracy and computational speed.
  - Minimises total generating costs each hour assuming ideal market
- Data collected:
  - Grid equivalents (PTDF's) for the different zones
  - Generation capacity and load forecasts for 2005-2030
  - Marginal costs for each generator type
  - Hydro data, including reservoirs and pumping capacity
  - Wind power scenarios from Tradewind WP2.

Intelligent Energy Europe

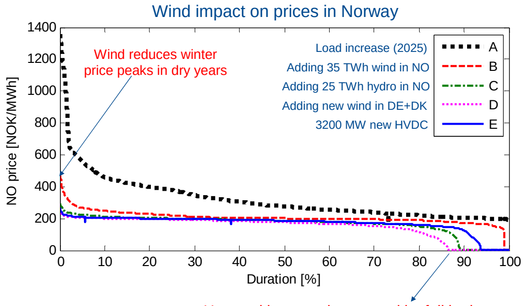
TradeWind — Further work

- The model will be applied (as part of WP5 and WP6) to study:
  - Overall power flows and network constraints with the chosen wind integration scenarios.
  - Effects of increasing transmission capacities on selected corridors.
  - Effects of enhanced power flow control.
  - Offshore grid scenarios.
- Comments and input are appreciated!

Intelligent Energy Europe

Balancing large amounts of wind power

Wind impact on prices in Norway



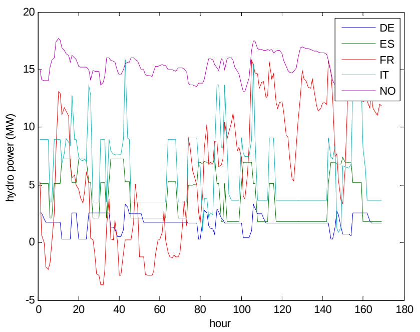
Hours with zero price caused by full hydro reservoirs and limited export capacity

Intelligent Energy Europe

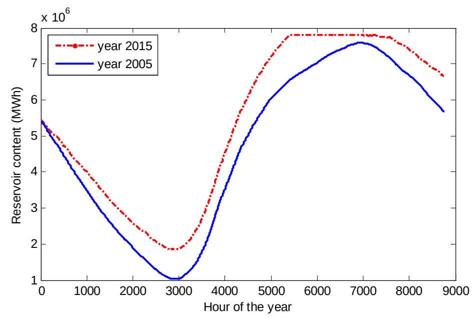
Extra slides

Intelligent Energy Europe

Hydro power snapshot of one week



Example results



Snapshot of UCTE PTDF matrix

		PTDFs						
ZONE1	ZONE2	GE__A1	LD__A1	GE__A2	LD__A2	GE__B	LD__B	GE__BH
A2	SV	0,01413	0,041324	0,144192	0,180202	0,003007	0,002971	-0,148044
A2	I2	0,046405	0,054007	0,076796	0,074767	0,011621	0,011493	0,006871
A2	SV	0,013385	0,023051	0,033522	0,036599	0,002358	0,002332	-0,036316
A1	D4	0,029328	0,030036	0,015017	0,014604	-0,001419	-0,001402	0,01662
A1	D4	0,04415	0,045215	0,022606	0,021984	-0,002136	-0,00211	0,02502
A1	D4	0,130612	0,134594	0,0641	0,062184	-0,004632	-0,004577	0,070638
A1	D4	0,104682	0,107873	0,051374	0,049839	-0,003713	-0,003669	0,056614
A2	D6	0,005123	0,013571	0,087349	0,083412	-0,018179	-0,017959	0,018032
A2	D6	0,00155	0,004105	0,026423	0,025232	-0,005499	-0,005433	0,005455
A2	S2	0,094071	0,097804	0,132777	0,121052	0,029941	0,029602	0,06726

K. Purchala, SUEZ Tractebel

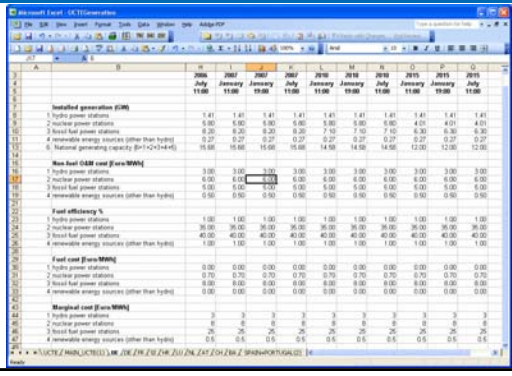
Physical cross-border lines model

- Most important lines modeled as *physical lines*
  - Cross-border and internal bottlenecks
- Modeling of internal network with equivalent generation & load nodes
- Where possible the aim is to model *physical lines* rather than aggregated transfer capacities ATC/NTC
  - The results are physical flows on cross-border lines
- If done right, accuracy is high (<2-3%, in extreme ~10%)
  - Depends on the number of generation and load zones

TradeWind — What is needed to produce network equivalents?

- One needs to have a full model
  - Chose the approximation level (zone definition)
  - Based on this, network reduction techniques can be used
- Zone definition is critical
  - Network topology information within the zone is lost
  - This loss of information needs to be as limited as possible

TradeWind — Generation capacities



	2006 July 11:00	2007 January 11:00	2007 January 19:00	2007 July 11:00	2010 January 11:00	2010 January 19:00	2010 July 11:00	2015 January 11:00	2015 January 19:00	2015 July 11:00
Installed generation (GW)										
1 hydro power stations	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41
2 nuclear power stations	5.80	5.80	5.80	5.80	5.80	5.80	5.80	4.01	4.01	4.01
3 fossil fuel power stations	8.20	8.20	8.20	8.20	7.10	7.10	7.10	6.30	6.30	6.30
4 renewable energy sources (other than hydro)	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
6 National generating capacity (6=1+2+3+4+5)	15.68	15.68	15.68	15.68	14.58	14.58	14.58	12.00	12.00	12.00
Non fuel O&M cost [Euro/MWh]										
1 hydro power stations	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
2 nuclear power stations	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
3 fossil fuel power stations	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
4 renewable energy sources (other than hydro)	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Fuel efficiency %										
1 hydro power stations	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2 nuclear power stations	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00
3 fossil fuel power stations	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
4 renewable energy sources (other than hydro)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel cost [Euro/MWh]										
1 hydro power stations	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2 nuclear power stations	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
3 fossil fuel power stations	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
4 renewable energy sources (other than hydro)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Marginal cost [Euro/MWh]										
1 hydro power stations	3	3	3	3	3	3	3	3	3	3
2 nuclear power stations	8	8	8	8	8	8	8	8	8	8
3 fossil fuel power stations	25	25	25	25	25	25	25	25	25	25
4 renewable energy sources (other than hydro)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

TradeWind

Wind and grid scenarios for Nordel

Bettina Lemström
VTT

3rd Synchronous Zone Seminar - Nordel
24.1.2008 Trondheim

Contents

Wind power scenarios in Tradewind
- capacity
- wind speed time series
- equivalent wind power curves

Analysis and simulations to be done
- transmission bottlenecks induced by wind power
- moving weather
- wind power and load variation
- smoothing effect

Wind power scenarios

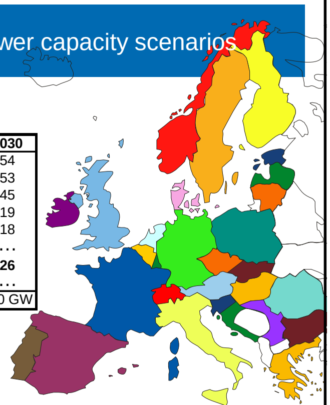
Installed capacity
- Target years 2005, 2008, 2010, 2015, 2020, 2030
- Three capacity scenarios for each year:
  - Low, Medium, High
- National and regional capacities for each type:
  - Offshore, onshore lowland and upland
- Based on national plans, targets, industry forecasts, likely policy developments
- Data received for EU27 plus Norway, Switzerland, Croatia, Serbia

Wind speeds
- 7 wind years: 2000 - 2006, ReAnalysis data

Wind power capacity scenarios

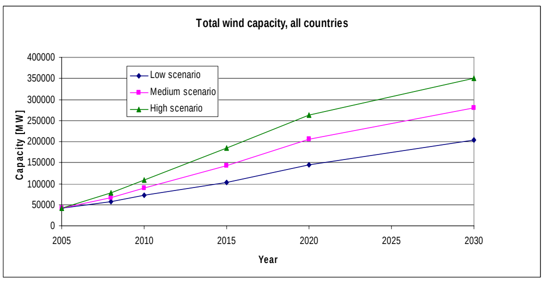
Medium scenario (GW)

	2005	2010	2020	2030
Germany	18	25	48	54
Spain	12	22	40	53
France	0,7	5	30	45
Italy	1,7	7	14	19
UK	1,2	8	16	18
…	…	…	…	…
Nordel	**4**	**7**	**17**	**26**
…	…	…	…	…
Total	42 GW	90 GW	206 GW	280 GW

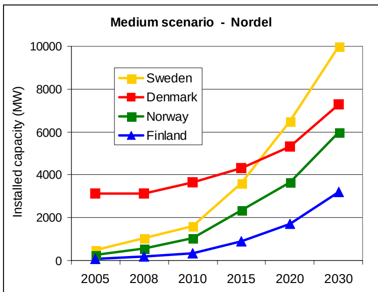


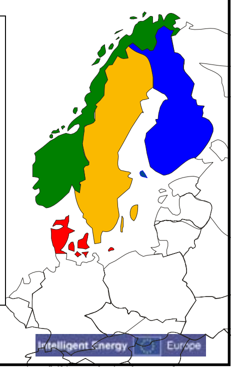
Deliverable D2.1 complete
(see Tradewind website)
•GH report 11914/GR/01C
•GH spreadsheet 11914/GT/03C

Wind power capacity scenarios

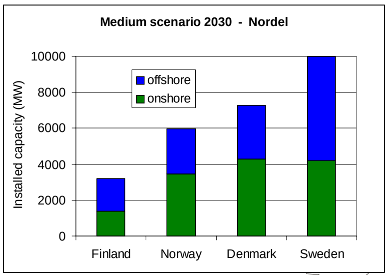


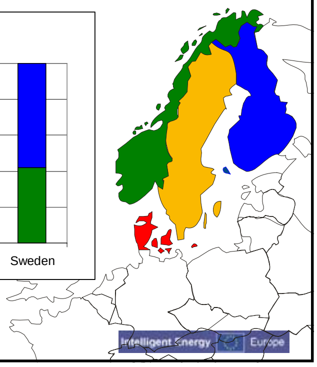
Wind power capacity scenarios





Wind power capacity scenarios





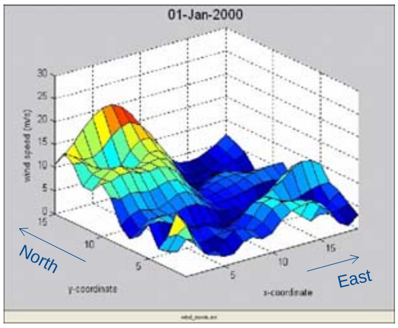
Wind speed time series

- Reanalysis data provided by National Oceanic & Atmospheric Administration (NOAA) through NOAA Operational Model Archive and Distribution System.
- The inputs to the model are from The National Center for Atmospheric Research (NCAR) and National Centers for Environmental Prediction (NCEP) database of observations.
- Reanalysis data:
  - 19 x 15 array of points across all countries of interest (map on next slide)
  - 7 years (2000 – 2006)
  - data available at 6-hour intervals: interpolated to 1-hour interval
- Use in simulations
  - one year time series
  - selection of meteorological 'events' (ie. passage of low pressures and storm fronts across large areas)

Wind speed time series

- Re-analysis Data Points (RDPs) (2.5°, ΔX~180 km, ΔY ~280 km)

Wind speed time series



Latitude = y-coordinate x 2,5 + 32,5N
Longitude = x-coordinate x 2,5 - 12,5W

Wind speed time series: validation

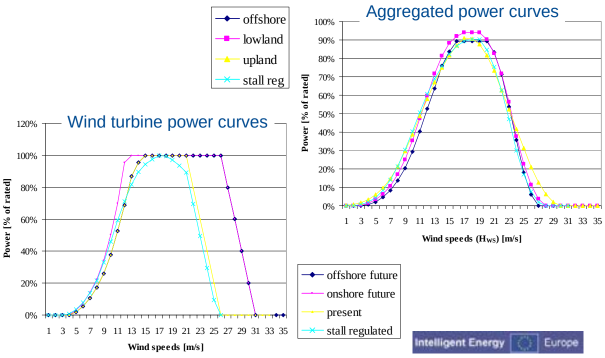
- Results of RDP data is compared against actual wind speed and wind production data from some countries
- Some differences: too low in Spain, too high in Germany. We are currently implementing scaling factors to correct this.
- Variability (i.e. change from hour to hour) is about right

Equivalent wind power curves

Purpose: Model for conversion of wind speed to power production for 'regions'

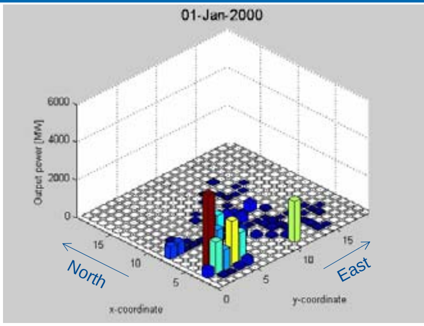
- Include array losses, topographic losses, electrical losses etc.
- Include aggregation across 'region', including availability effects
- Changes in power curve and hub height in future
- Separate models for onshore (lowland, upland) and offshore
- Deliverable D2.4 complete: GH document 11914/BT/02B

Equivalent wind power curves



Intelligent Energy Europe

Wind power series



Intelligent Energy Europe

Analysis and simulations

1. Identification of wind power induced bottlenecks for different generation, load, wind power penetration cases
   - simulations with the grid model
   - one year time series for different scenarios
   - look at congested lines, reinforcement needs
2. Moving weather - assess effect of special events on cross boarder flows
3. Effect of improved exchange on capacity credit and smoothing of wind power

Intelligent Energy Europe

Moving weather

Special events:

Strong winds → temporarily much wind power

Storms → shut-down of wind farms, fast reduction of power

Rapid changes in power affect:

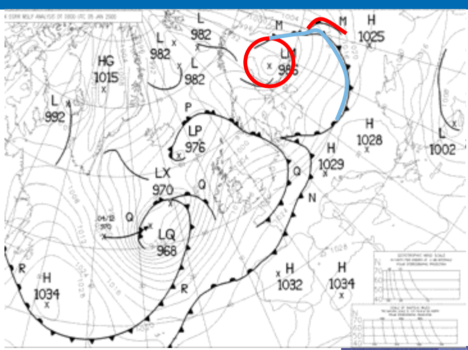
- generation & load balance of a country/power system:
  - import ↔ export
- cross boarder flow:
  - temporal congestion, change in direction and amount

Events selected from data 2000-2006 (ReAnalysis, weather maps)

Simulations with the grid model

Intelligent Energy Europe

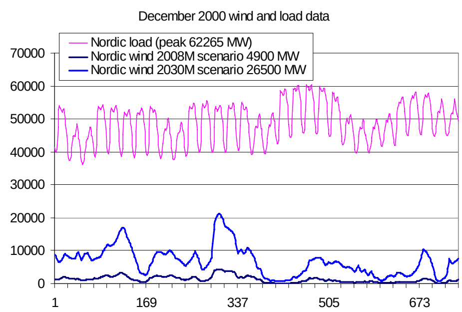
Moving weather



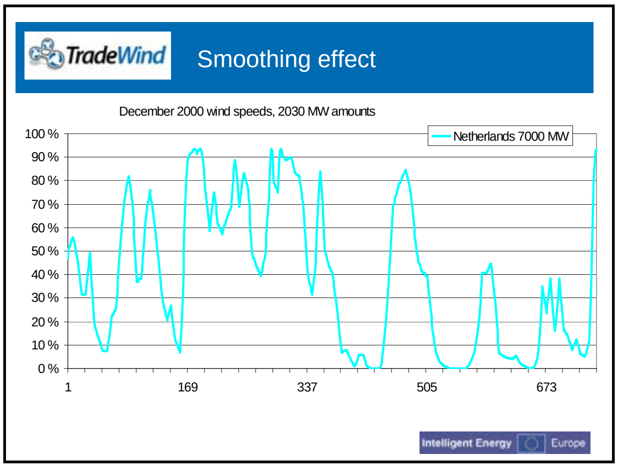
http://www.wetterzentrale.de

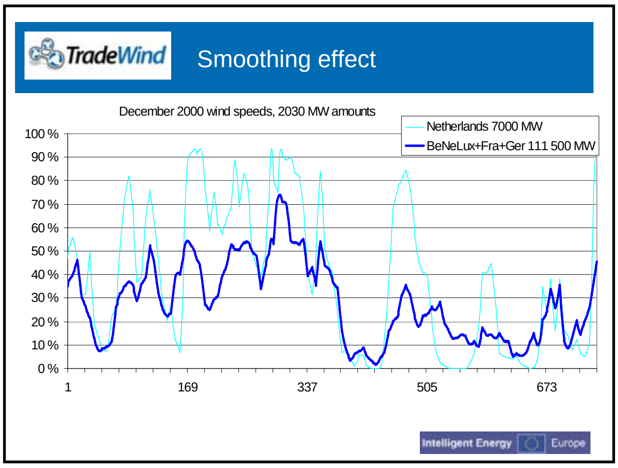
Intelligent Energy Europe

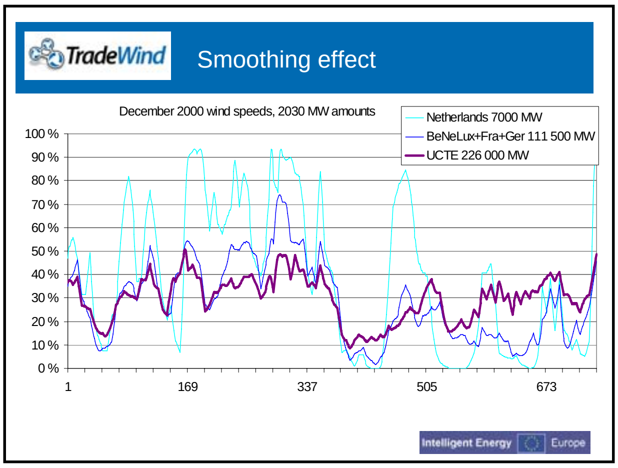
Wind power and load variation - example Nordel

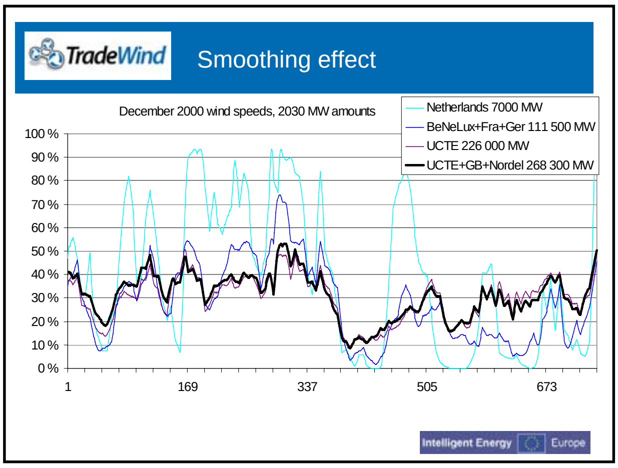


Intelligent Energy Europe


TradeWind
Smoothing effect
December 2000 wind speeds, 2030 MW amounts
Netherlands 7000 MW
100 %
90 %
80 %
70 %
60 %
50 %
40 %
30 %
20 %
10 %
0 %
1
169
337
505
673
Intelligent Energy Europe


TradeWind
Smoothing effect
December 2000 wind speeds, 2030 MW amounts
Netherlands 7000 MW
BeNeLux+Fra+Ger 111 500 MW
100 %
90 %
80 %
70 %
60 %
50 %
40 %
30 %
20 %
10 %
0 %
1
169
337
505
673
Intelligent Energy Europe


TradeWind
Smoothing effect
December 2000 wind speeds, 2030 MW amounts
Netherlands 7000 MW
BeNeLux+Fra+Ger 111 500 MW
UCTE 226 000 MW
100 %
90 %
80 %
70 %
60 %
50 %
40 %
30 %
20 %
10 %
0 %
1
169
337
505
673
Intelligent Energy Europe


TradeWind
Smoothing effect
December 2000 wind speeds, 2030 MW amounts
Netherlands 7000 MW
BeNeLux+Fra+Ger 111 500 MW
UCTE 226 000 MW
UCTE+GB+Nordel 268 300 MW
100 %
90 %
80 %
70 %
60 %
50 %
40 %
30 %
20 %
10 %
0 %
1
169
337
505
673
Intelligent Energy Europe

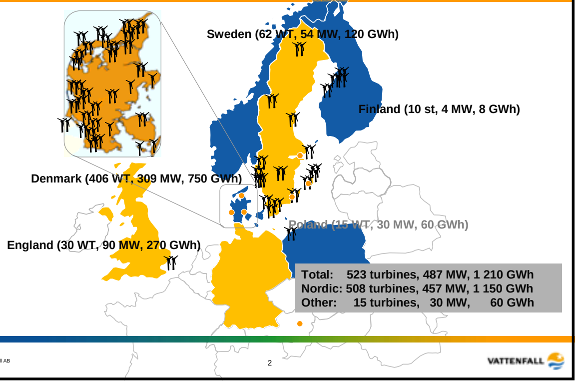

TradeWind
Thank you !
Intelligent Energy Europe

Kriegers Flak

TradeWind Seminar
24 January 2008
Göran Loman

VATTENFALL

Vattenfalls wind power: 1.2 TWh



VATTENFALL

Vattenfalls project Kriegers Flak

The windfarm
- In the EEZ, 30 km from coast
- Water depth of 17-40 m
- 128 turbines
- 5 MW each
- 2,1 TWh/y

Status
- Received permission from the Government
- Working with site assessment
- Waiting for net concession

VATTENFALL

What kind of turbine?

- Approved technology
- More than 5 MW

- Do we have a conflict here?

VATTENFALL

Grid connection

AC
- 640 MW, 135 kV; 2 cables each to Arrie and Trelleborg
- 450 MW, 135 kV; 3 cables to Arrie

HVDC, VSC
- 700 MW, ±300 kV; 1 cable to Arrie
- 450 MW, ±150 kV; 1 cable to Arrie

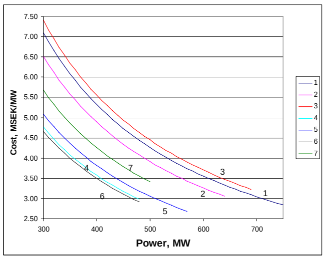
Combinations

VATTENFALL

Grid connection
How to choose

Depends on
- Size of farm
- Copper prize
- Market situation
- Technical development

Alt	Power	Configuration
1	700 MW	1 DC to Arrie, ±300 kV
2	640 MW	2 AC to Arrie, 135 kV 2 AC to Trelleborg, 135 kV
3	640 MW	1 DC to Arrie, ±150 kV 2 AC to Trelleborg, 135 kV
4	450 MW	3 AC to Arrie, 135 kV
5	450 MW	1 DC to Arrie, ±150 kV
6	450 MW	2 AC to Arrie, 135 kV 1 AC to Trelleborg, 135 kV
7	450 MW	1 DC to Arrie, ±150 kV 1 AC to Trelleborg, 135 kV



VATTENFALL

Site Assessment

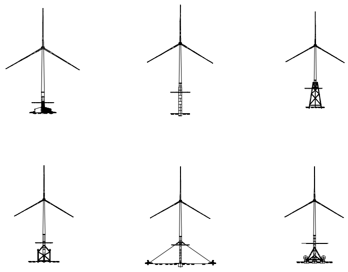
- Geotechnical survey
  - Geophysical measurements
  - CPT, vibrocores
  - Borings
- Hydrographical measurements
  - Waves
  - Currents
- Meteorological measurements
  - Wind
  - Temperature

  VATTENFALL

Foundation

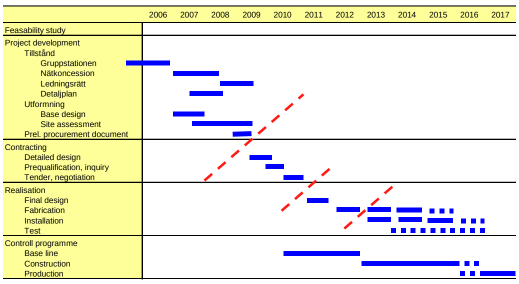
Foundations
- Gravitation
- Monopile
- Jacket
- Tripod
- Combinations

Concept study 2008
- Design
- Evaluate



  VATTENFALL

Time plan



  VATTENFALL

More projects

- Germany
  - Baltic 1, 50 MW
  - Kriegers Flak 1, 400 MW
- Sweden
  - Kriegers Flak 2, 640 MW
- Denmark
  - Kriegers Flak 3, 400 MW

  VATTENFALL

Some years from now…

  VATTENFALL

Thank you!

  VATTENFALL

ewis
european wind integration study

European Transmission System Operators

European Wind Integration Study (EWIS) Towards a Successful Integration of Wind Power into European Electricity Grids

TradeWind NORDEL Seminar, 24th of January 2008

---

ewis – european wind integration study

EWIS – A Common Study of all Synchronous Areas within Europe

- Common initiative of all TSOs
- Time horizon 2008 – 2015 …
- 100% funded and supported by EC
- Close cooperation to external stakeholders
  - Network operators (TSOs and DSOs)
  - Wind power producers and wind turbine developers
  - Market participants
  - Relevant studies on Wind integration
    - TradeWind, IEA-Task 25 …
  - Consumers
  - Regulatory representatives
  - European Commission
  - National Governments and authorities…

---

ewis – european wind integration study

Lead Transmission System Operators

Lead transmission system operators	Country
Elia System Operator (Coordinator)	Belgium
ČEPS, a.s.	Czech Republic
Energinet.dk	Denmark
E.ON Netz GmbH	Germany
RWE Transportnetz Strom GmbH	Germany
Vattenfall Europe Transmission GmbH	Germany
EirGrid plc	Ireland
Hellenic Transmission System Operator	Greece
National Grid	United Kingdom
PSE-Operator	Poland
Red Eléctrica de España	Spain
Rede Eléctrica Nacionalis	Portugal
Réseau de Transport d'Electricité	France
TenneT TSO B.V.	Netherlands
Verbund – Austrian Power Grid AG	Austria

---

ewis – european wind integration study

Objectives of the Study

To seek proposals for a generic and harmonized European wide approach towards wind energy issues addressing:

- operational/technical aspects including grid connection codes,
- market organization
- regulatory/market-related requirements,
- common public interest issues general aspects impacting the integration of wind energy

---

ewis – european wind integration study

General Project Organisation

Project Assembly

- **PSC** Project Steering Committee
- **PM** Project Management
  - **PMT** Project Management Team (PM, WG-Leaders, PSC-Convener)
- **PCB** Project Consultation Board

Steering Level

WG 1	WG 2	WG 3	WG 4	WG 5	WG 6
Present Situation & Market Aspects	Scenarios & Exchange Schedules	Power System Analysis	Operational Aspects	Cost Analysis	Legal Aspects & Communication

Technical Level

General project organisation: Common structure from the working to the steering level

---

ewis – european wind integration study

Present Status and Market Aspects

Objectives

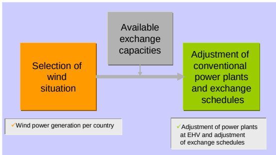
- To analyse physical and market aspects related to the current state of wind energy in Europe.
- To investigate the evolution of wind energy issues, the expectations for the future and the different circumstances in each country and how they are managed.

- Wind power development in Europe: 2008 & 2015
- Regulatory and Market Framework: changes
- Grid Code Requirements
- Operational and control issues
- System planning and network development
- Interconnections to neighboring countries
- Studies related to wind power integration

ewis
european wind integration study

Scenarios and Exchange Schedules

… focuses on setting up scenarios and performing market simulations in order to assess the wind power production, production from conventional power plants and the exchange schedules at the point in time of the scenarios for the year 2015.



- Two base cases will be set up:
  - a) Year 2015: situation according to most likely development
  - b) Year 2015: situation according to a high wind power development
- The base case a) represents the business as usual situation with the most likely development of the power system. In contrast to it, the base case b) represents the optimistic national wind power developments.

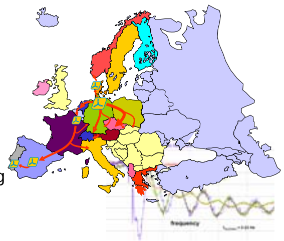
ewis
european wind integration study

Power System Analysis

… based on the premises of unchanged reliability of the European electric power system and on maintaining safe and reliable interconnected operation among European partners.

Framework conditions and assumptions for technical criteria, analyses and evaluations:

- Determination of the transmission system extension necessary for covering (n-1)-secure transmission
- Dynamic investigations concerning adherence to reliable limit values in the case of individual system faults.



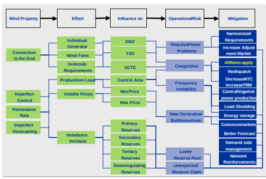
ewis
european wind integration study

Operational aspects

- Wind energy production is growing at a rapid pace
- There is a diversity and complexity of rules and regulations (incentives for large scale wind integration) in the Member States
- No single level playing field for TSOs, Regulators and Market actors: "Europe is not harmonised yet"
- There is no unique and perfect solution set to mitigate risks

Main identified common risks:

unscheduled transit flows that cause congestions
lack of system reserves

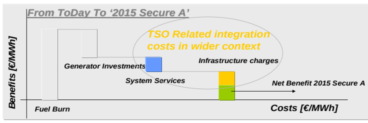


ewis
european wind integration study

Cost Analysis

Objectives

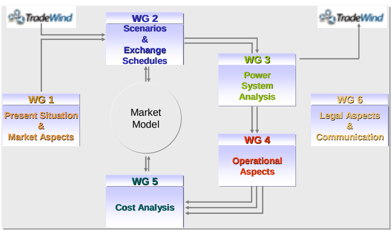
- Identify all relevant system integration costs from a system perspective
- Quantify where needed the major system integration costs from a risk mitigation perspective
- Determine cost optimal risk mitigation strategies



- Allocate costs and benefits to major stakeholders
- Different sets of risk mitigation measures and sensitivities (fuel costs, wholesale prices, infrastructure)
- Assess non-monetary benefits in terms of emission reductions, …

ewis
european wind integration study

Working group activities



- Speeding up the approval procedures for new grid infrastructure to be in step with RES development …
- Improve connection requirements for wind turbines …
- Harmonised European support scheme for Renewable Energy Sources …

- Relevant scenarios related to technical and market aspects
- Need for counter-measures and optimisation strategies
- Need for grid reinforcement and operative measures
- Need for security management
- Analysis of integration costs
- Need for balancing power
- Harmonised requirements for Wind turbines

ewis
european wind integration study

Working Schedule

Interim Report 15.06.2008 | Final Report 15.10.2009

MS 1 12/2007	MS 2 08/2008	MS 3 10/2008	MS 4 11/2008	MS 5 02/2009
Present Situation & Market Aspects	*Base Case Scenarios*	*Risk Analysis*	*Risk Mitigation*	*Pan European Aspects*
• Wind development • Regulatory and market framework • Incentive Schemes • Grid Codes in Europe • Grid Planning Practices • Influence on Interconnections	• Base case and initial scenario setting • Market model selection • Report on Scenarios and Exchange Schedules	• Congestion list including n-1 analysis and transnational influences • Frequency control risks • Transient Stability Risks • Economical risks for TSOs and market participants	• Need for grid reinforcements • Need for reactive power compensation and voltage control • Wind forecasting systems • Load following for power plants and demand side management •Capacity assessments and curtailments	• Harmonised grid code requirements • Financial incentive schemes • Market models • Energy storage use and development

ewis
european wind integration study

EWIS – The Reference Integration Study on European Level

… Broadly accepted and supported by major stakeholders interested in wind power integration …

Stakeholders

- DG Transport & Energy - DG TREN
- DG Environment - DG ENV
- DG Research
- European Wind Energy Association - EWEA
- TradeWind
- European Federation of Energy Traders - EFET
- Industrial Federation of Industrial Energy Consumers – IFIEC
- Union of the Electricity Industry - Eurelectric
- European Energy Institute
- European Parliament Committee Industry, Research and Energy
- International Energy Agency - IEA - www.iea.org

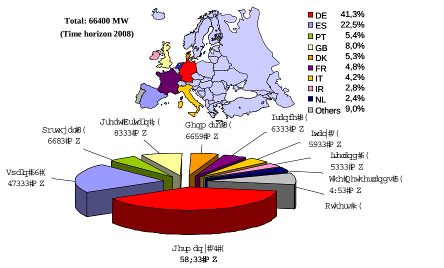
ewis
european wind integration study

EWIS Online …

ewis
european wind integration study

Present Situation (MS1) – First Results Wind Power Integration all over Europe

High wind power increase from 41 GW in 2005 to nearly 67 GW already in 2008 with a concentration in only 3 countries which represent more than 70% of the total installed capacity



ewis
european wind integration study

TSO Related Measures and Activities on wind power integration (all synchronous areas)

A *Additional requirements for wind power generation in those countries which represent more than 70% of the total installed capacity in Europe based on the results on national studies and studies on European level (EWIS) in 2007*

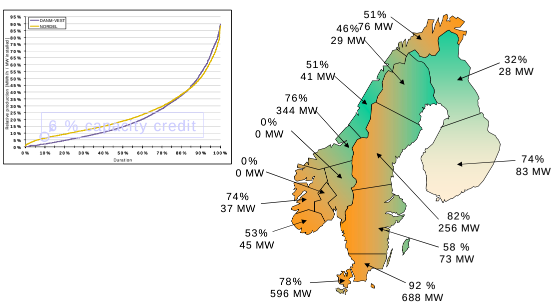
B *European Wind Integration study EWIS confirmed the grid enforcement already investigated on national level. Responsible TSOs has been started the necessary grid enforcement activities in those regions.*

C *Congestion management: Common measures for power flow control by phase shifters in those regions with high surplus of wind power generation results in large temporary flows to neighbouring transmission systems*

D *FACTS devices for reactive power compensation are planned and partly in operation to prevent a decrease of voltage quality and a increase of grid losses in case of high wind power production*

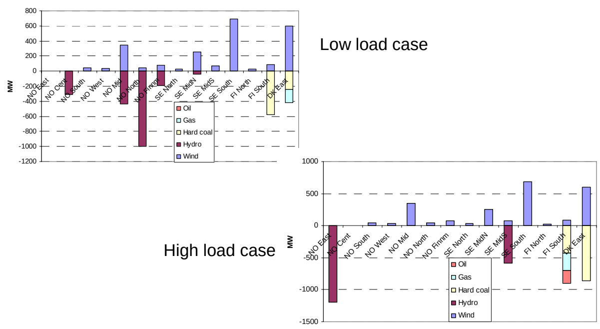
ewis
european wind integration study

Scenario for Wind Power Generation 2008 - Nordel



ewis
european wind integration study

Changes in Power Production



Findings Nordel system

A *Low wind power penetration (3000 MW excl. DKW) in the Nordic system 2008 shows no significant impact on the Nordel power system*

B *Small correlation between wind power production in the Nordel system and exchange to the UCTE. Large correlation between wind power production in Denmark and Germany and exchange between Nordel and West Denmark.*

C *No transmission line overload were identified in n-1 studies. No voltage problems identified*

D *Capacity credit 6 % based on time series analysis*

TSOs Overview

A *The European transmission networks are playing a very important role in bringing wind power to market efficiently and economically*

B *TSOs are being proactive in initiating a harmonised approach to addressing the various network issues concerning wind power integration*

C *TSOs very much look forward to working with our wind stakeholders on wind power integration into the European Transmission Network*

D *Given that Tradewind is now nearing completion, TSOs intend to pick up the TradeWind findings and to take wind integration forward*

Collaboration & Event Timeline

Event	Date	EWIS Action
EUROLECTRIC Conference **Presentation**	18/04/07	EWIS report phase I - Wilhelm Winter, EWIS
EWEC 07, Milano **Paper & Panel Session – IEA Task 25**	08/05/07	EWIS present situation operation & risk mitigation -Wilhelm Winter, EWIS
Green Power Marketing, Lausanne **Presentation**	13/09/07	EWIS present situation operation & risk mitigation -Denis Klaar, Tennet
Greennet study conference – Stuttgart **Presentation**	18/10/07	EWIS present situation and outlook, TSOs activities - Presented by Wilhelm Winter
TradeWind seminar Glasgow (BWEA Conference) **Presentation**	8/10/07	European Wind Integration Study - Lewis Dale
EWEA Offshore Presentation Conference, Berlin - TradeWind **seminar**	6/12/07	European Wind Integration Study - Gerald Maas, UCTE; Wilhelm Winter, EWIS
TradeWind seminar Trondheim **Presentation**	**24/01/08**	**European Wind Integration Study** **- Frederic Norlund**
RESPOND Workshop, Madrid **Presentation**	07/02/08	European Wind Integration Study - Luis Imaz
EWEC 08 – International Integration Studies **Paper & Presentation**	01/04/08	European Wind Integration Study EWIS
IEEE Super Session on wind power integration, Pittsburgh **Paper & Presentation**	22/06/08 26/06/08	European Wind Integration Study EWIS
NERC – North American Electric Reliability Corporation **Cooperation**	Ongoing	Contact: Wilhelm Winter, EWIS
TradeWind Study **Cooperation**	Ongoing	Contact: EWIS PMT: Wilhelm Winter, EWIS
IEA Task 25 **Collaboration**	Ongoing	Contact: Frank Vermeulen, ELIA

Contact Project Management Office

Dr. **Wilhelm Winter**
EWIS Project Manager
European Wind Integration Study
Boulevard Saint-Michel, 15
B-1040 Brussels, Belgium
info@etso.org - info@ucte.org

Project Management Office
Mr. **Kedar Kolharkar**
Bernecker Str. 70
D-95445 Bayreuth
+49 (921) 915 4166
Fax: +49 (921) 915 4149
Mobil: +49-160-97-838-919
mailto:wind-integration.eu

Nordel transmission planning – wind integration

Fredrik Norlund
Svenska Kraftnät

Trondheim, 24 January 2008
TradeWind 3rd synchronous zone seminar: Nordel

Organisation for the Nordic Transmission System Operators

1

Nordel

The collaboration organisation of the Transmission System Operators of Denmark, Finland, Iceland, Norway and Sweden

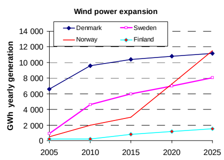
Co-operation mainly within:

- Operational security
- Network planning
- Market functioning

Organisation for the Nordic Transmission System Operators

2

Wind power development in the Nordel area

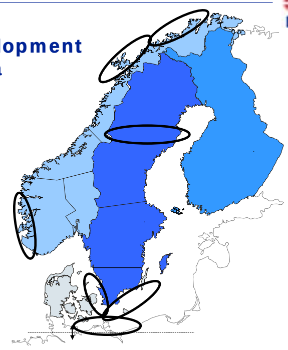


Figures from the Nordic grid master plan 2008

Organisation for the Nordic Transmission System Operators

3

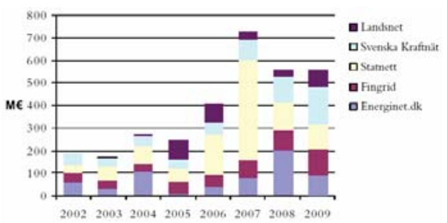
Wind power development in the Nordel area



Organisation for the Nordic Transmission System Operators

4

Grid investments



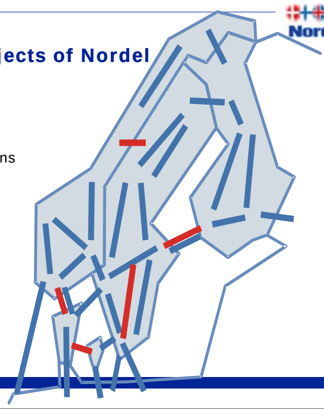
Organisation for the Nordic Transmission System Operators

5

The strategic projects of Nordel

Investments of approx. 10 billion SEK totally

Improved market conditions and system robustness

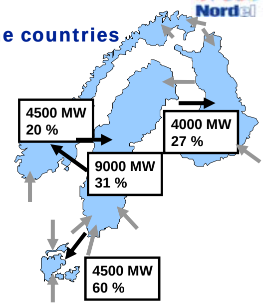


Organisation for the Nordic Transmission System Operators

6

Large capacity between the countries

The EU-commission has recommended at least 10 % trade capacity in relation to national maximum consumption

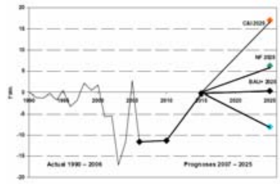


Nordic grid master plan 2008

Objective
Identify cross-section reinforcements which will be cost effective according to prospectives for 2015 and 2025. This has been carried out by a socio economic cost-benefit calculation.

Scenarios (TWh wind power)

BAU	27
NF	34
C&I	47

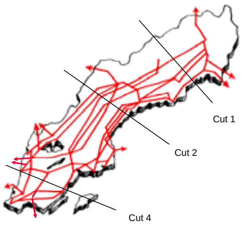


Results will be reported soon

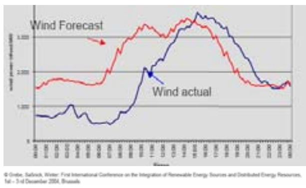
Internal planning

Example: Relevant studies in Sweden

- Cut 2
- South of Sweden



Balancing power



New study focusing on need of new balancing power when introducing large amounts of wind power in the Nordic system. Report to the Swedish Government this spring.

Nordic Grid code

Can be down loaded from our web site

www.nordel.org

TradeWind – Market

Market mechanisms facilitating efficient system operation with large amounts of wind power, Achim Woyte, 3E

Grid and market challenges with large scale wind development within Nordel, Jan Bråten, Statnett

Development of wind farms in a market perspective,
Erlend Broli, Statkraft

TradeWind

EUROPEAN POWER MARKETS IN MOTION

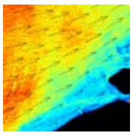
Requirements for a Trans-continental Trade of Wind Power

Achim Woyte

3E sa
Brussels, Belgium
http://www.3E.eu/

3rd Synchronous Zone Seminar, Nordel, Trondheim, 24 January 2008

OUTLINE

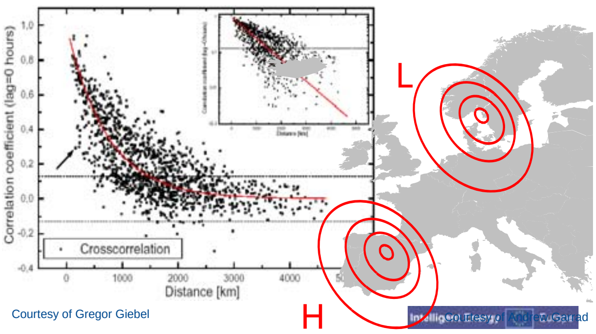


- Rationale
  - spatial decorrelation
  - previsibility
- European integration process
  - status
  - trends
  - meaning for wind power
- TradeWind approach
  - market analysis with large wind penetration

Intelligent Energy Europe

SPATIAL DECORRELATION

... most interesting over large distances.



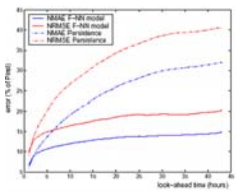
Courtesy of Gregor Giebel

PREVISIBILITY

... the shorter ahead the better.

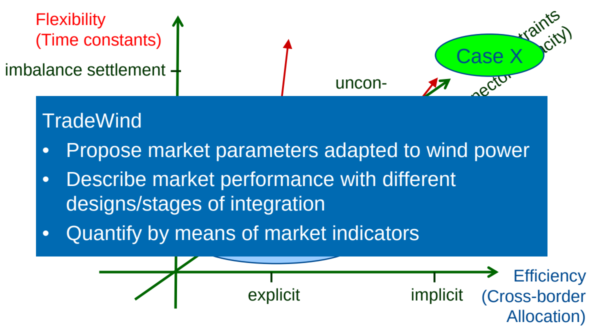
- 40h ahead: mean absolute error >10%
- 3h ahead: mean absolute error <<10%
- Energy markets in Europe:
  - "spot": d-1@12am
  - intra-day adjustment: ½ - 3h ahead
  - balancing service <1h

⇒ Market integration as close as possible to real time !



Intelligent Energy Europe

MARKET PARAMETERS



TradeWind
- Propose market parameters adapted to wind power
- Describe market performance with different designs/stages of integration
- Quantify by means of market indicators

Intelligent Energy Europe

TODAY AND IN FUTURE ...

- mostly national spot markets
  - day-ahead
  - sometimes intra-day
- explicit allocation of interconnectors
- few coupled markets
  - NordPool (day-ahead & intra-day)
  - tri-lateral market coupling (TLC: Ne, Be, Fr)
- Future
  - larger market regions

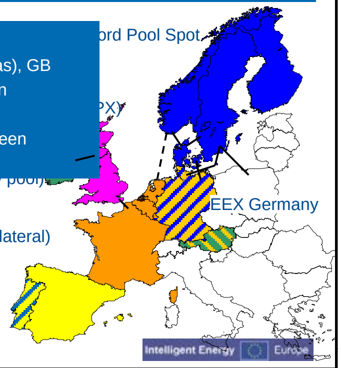
Intelligent Energy Europe

MARKET ZONES IN EUROPE

TradeWind

- Day-ahead access within zone
- Intra-day trade: NordPool (Elbas), GB
- Interzonal trade: explicit auction

- Germany/NorNed: bridge between Nord Pool and TLC → 2009 ?



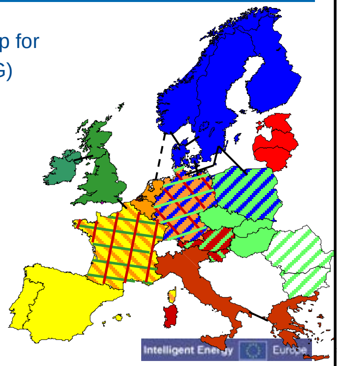
Intelligent Energy Europe

REGIONAL MARKETS

TradeWind

European Regulators' Group for Electricity and Gas (ERGEG) (http://www.ergeg.org/)

- Central-West
- Northern
- UK & Ireland
- Central-South
- Southwest
- Central-East
- Baltic



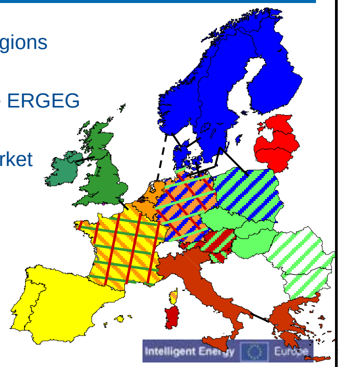
Intelligent Energy Europe

WIND POWER REGIONS

TradeWind

TradeWind Wind Power Regions

- larger regions beyond the ERGEG
- new interconnectors
- including a North Sea market (offshore grid)



Intelligent Energy Europe

REALISTIC TIME LINE

TradeWind

EGREG Regional Markets develop punctually

- Central-West and Northern markets very soon: pentalateral coupling planned for 2009
- Southwest, UK&Ireland+France a few years after

- large regions in place within 10 years ?

Intelligent Energy Europe

TRADEWIND APPROACH

TradeWind

- Sensitivity analysis for EU energy scenarios (2030)
- Boundary conditions
  - interconnector capacity
  - large wind power penetration
- Variation of
  - gate closure times (flexibility)
  - degree of EU market integration (efficiency of interconnector allocation)
- Market indicators
  - system costs
  - market value of wind power
  - price volatility,etc

Intelligent Energy Europe

CONCLUSIONS & OUTLOOK

TradeWind

- Efficient wind power integration requires
  - flexible market access
  - trading facilities all over Europe
- European markets integrate fast
- TradeWind wants to
  - propose adapted market parameters
  - describe market performance with different designs/stages of integration
  - quantify by means of market indicators

Intelligent Energy Europe


Questions & Discussion

Grid and market challenges with large scale wind development

TradeWind Seminar, Trondheim

January 24th, 2008

Jan Bråten

Statnett

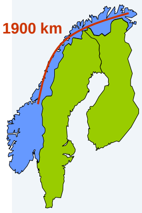
Statnett´s objective:

- To **optimize the economic efficiency** of the power sector while maintaining system reliability
  - Facilitate efficient **development** (investments).
    - Price signals. Advice regarding localisation of new generation. Grid expansion
  - Economic efficient **operation** of the power system.
    - Congestion management, losses

Statnett

Efficient development of wind power

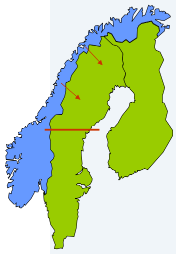
- Where should new wind power come? And how much (considering congestions)?
  - Take transmission costs into account!
    - Losses, congestions and cost of lines + environment
  - Cost of congestions depends on how efficient we can exploit the flexibility of other generators and demand. In Norway: in particular flexible hydro
- The coordination in time between grid investments and transmission investments
  - Mutually dependent investments should be coordinated
  - Long lead times combined with uncertainty create difficulties today



Statnett

Efficient congestion management allow more wind power

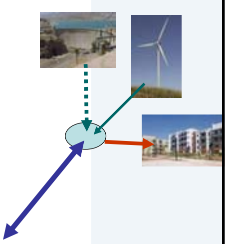
- Norway: Flexible hydro reservoirs can operate as a local "storage" of wind power
- What arrangements (e.g. market design) are best suited to make sure storages are used efficiently?
- Efficient congestion management reduce costs of bottlenecks
  - Allowing more wind power



Statnett

Efficient congestion management allow more wind power

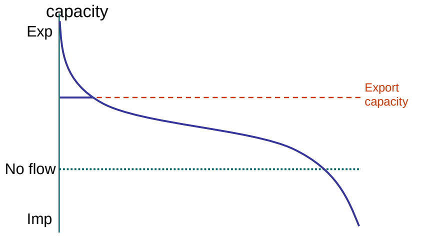
- Assume:
  - Area with surplus of energy (GWh), cost of wind power is low, hydro with storage, some consumption
- Two sides of the coin:
- How much wind power is optimal for a given "export capacity" (transmission capacity)?
- How much transmission capacity should be built for a given installation (MW) of wind power?
  - Wind power capacity may be *scaled* more easily than transmission
  - *Uncertainty* => better with gradual expansion of wind power based on experience and changes in demand

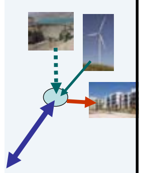


Statnett

Efficient congestion management allow more wind power

- Possible duration curve for desired export and real export with a given volume of wind power capacity



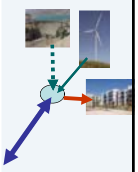


Flexible hydro may reduce cost of congestion to near zero

Statnett

Possible solutions

- ECON Study:
  - **Price areas** give good incentives in general
    - Some difficulties in smaller areas
  - **Counter trading** likely to give a lot more problems
    - Suboptimal production profile over seasons
- Small price areas are controversial, but seems to be more efficient in general
  - How small?
- Other methods?
- Generally: price signals are important to promote efficient use of all resources including demand and direction of flow
  - Discussion is widely relevant – e.g. wind power in Northern Germany

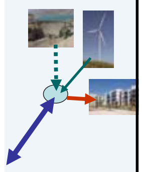


Statnett

…and one more challenge

- Uncertainty about wind power production one day ahead
- Trading closer to the operation hour important to make efficient use of the transmission capacity
- E.g. expected congestion (day ahead) removed by lower wind power production
  - ⇒ Important to allow for more "export" of hydro power if that is profitable

⇒ **Market design is important!**



Statnett

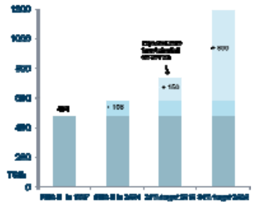
DEVELOPMENT OF WIND FARMS IN A MARKET PERSPECTIVE

Erlend J. Broli, Statkraft

Statkraft PURE ENERGY

AMBITIOUS TARGETS FOR RENEWABLE ENERGY

- 20% of primary energy consumption indicate up to 35 % renewable electricity
- The growth rate must increase by at least a factor 3 compared to1997-2004
- Wind power is expected to contribute to > 50% of the growth
- Offshore wind is expected to contribute to 10-20 % of 2007 – 2020 growth



Kilde: Statkraft

side 2 DETTE ER EN DUMMYTITTEL

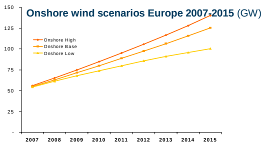
GROWTH FORECAST FOR WIND POWER IN EUROPE

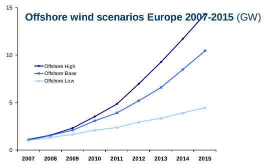
Onshore:

- Onshore wind far larger than offshore the next 10 yrs.
- Germany close to saturation
- Spain and France with the biggest growth
- Sweden will drive Nordic growth the coming years
- Maturity and Cost advantage above other renewable technologies main driver

Offshore:

- Denmark has dominated to date with two large demonstration projects
- UK will overtake at the end of 2007 and will maintain market lead to at least 2010
- Increased activity in Netherlands and Sweden is currently accelerating growth
- Increased feed-in tariffs accelerates growth in the German market
- Still not past demonstration phase, technical risk still significant

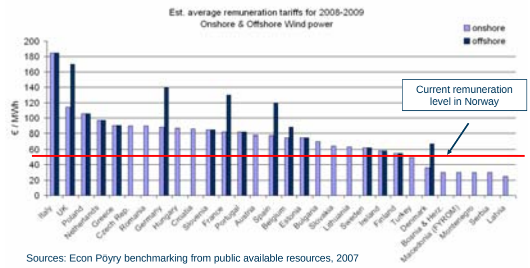




Source: Emerging Energy Research

side 3 DETTE ER EN DUMMYTITTEL

REMUNERATION FOR WIND POWER



Sources: Econ Pöyry benchmarking from public available resources, 2007

side 4 DETTE ER EN DUMMYTITTEL

WE ADVOCATE FOR A HARMONISED MARKET BASED APPROACH

- **Significantly less expensive and more robust than other policy options**
- **Reduced environmental impact of new power generation**
- **Supports the further development of the Internal Energy Market through integration and interaction with power and carbon markets**
- **Creates European arena for innovation and technology development**
- **Improves the investment incentives for investors in renewable energy across Europe**

Discussions between Sweden and Norway about a common market for certificates have been restarted!

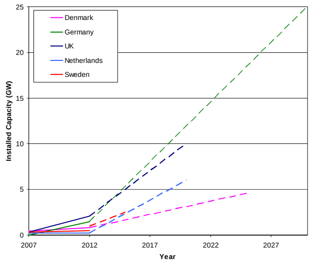
side 5 DETTE ER EN DUMMYTITTEL Certificate Scheme

STATKRAFTS EXPERIENCES

Norway	Sweden
Target set for 2010, no long-term ambitions	Ambitious targets – 30 TWh by 2020
Doubt whether target still applies	Dedication towards goals
Increasing resistance locally	Positive atmosphere locally
Increasingly complex permitting process	Expedient permitting process
Little will to make decision regarding grid that benefits wind	Positive attitude to find solutions for the Grid that benefits wind
Inadequate and ever changing incentive scheme	Stable and long-term green certificate market

side 6 DETTE ER EN DUMMYTITTEL

STRONG PULL FOR OFFSHORE WIND



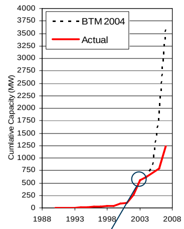
	2007 Operational	2012 Projection	Long-term Target / Aspiration
DK	423 MW	0.8 GW	4.6 GW (2025)
DE	3 MW	1.5 GW	25 GW (2030)
UK	304 MW	2.0 GW	~10 GW (2020)
NL	127 MW	0.3 GW	6 GW (2020)
SE	23 MW	1.0 GW	2,5 GW (2015)

- Solid Lines: Projections to 2012
- Chained Lines: National Target or Aspiration

Statkraft

OFFSHORE WIND DEPLOYMENT IN EUROPE

Cumulative Totals
25 Projects
1232 MW

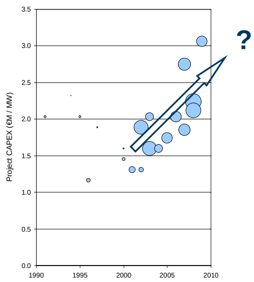


A False Dawn

Statkraft

INCREASING COSTS ➔ WEAKENED ECONOMICS

- Withdrawal of EPC contract offers
- High early competition and losses
  - market readjustment
- Onshore WTG market
  - demand >> supply
- Offshore WTG market
  - co-incident with onshore
- BoP Supply Chain
  - limited vessels, cables and trafos



Statkraft

PREREQUISITES FOR REACHING AMBISIONS

- Third Phase of maturity emerging: UK R2, R3 and German Pilot projects
- Re-emergence of EPC
- Technical Innovation leading to reduced costs
- Increased supply chain capacity and competition
- New markets emerging; eg. France, Spain, Italy…
- Increased grid capacity and flexible production in key geographical areas
- Regulatory framework facilitating large scale deployment of offshore wind power

Statkraft

REGULATORY FRAMEWORK – LESSONS LEARNED

Inhibitors	*Best practice*
Inappropriate Legislative Frameworks	Strong Political Will
Unclear authority and jurisdiction offshore	Simplify and Centralise
Grid Access Difficulties	Strategic Spatial Planning
Political and Regulatory Instability	Capital Support and Grid Ownership
Inappropriate Site Awards	Effective Incentive Mechanism
Environment and other conflict of interest	Encourage Technical Innovation
	Allow Foreign Involvement
	International Competitiveness

Statkraft

AN OFFSHORE STRATEGY FOR NORWAY?

- Establish an extensive Research and demonstration program for offshore wind
- Prepare a Strategic spatial plan for the North sea to avoid the obvious conflicts
- Prepare a legal framework for offshore wind that regulates site awards, permitting process and grid related issues
- Define economic incentives early to facilitate both demonstration and commercial deployment
- Start now but have a realistic view on when the technology can be commercial

Statkraft


PURE
ENERGY

Vindressurser

Terrengets betydning for posisjonering av vindturbiner,
PhD student Kjersti Røkenes, NTNU

Ising på vindturbinene i Nygårdsfjellet vindpark,
Matthew Homola, Høgskolen i Narvik

Vind- og iskart for Norge, Øyvind Byrkjedal, Kjeller Vindteknikk

Offshore vindressurskartlegging, Erik Berge, Kjeller Vindteknikk

Offshore turbulens – Erfaringer fra vindmålingene på Frøya,
Jørgen Løvseth, NTNU

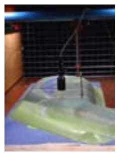
Terrengets betydning for posisjonering av vindturbiner

Kjersti Røkenes
PhD student, Strategisk Vindkraftprogram 2003-2007

Institutt for energi- og prosessteknikk
Veileder: Per-Åge Krogstad

Vindkraft FoU Seminar, 25. januar 2008

Innhold



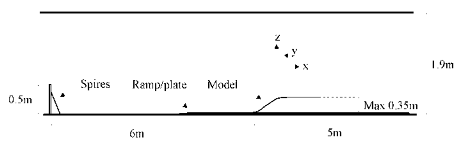
- Bakgrunn for studiet
- Eksperimentelt oppsett og terrengmodell
- Resultater - terrengeffekter
- Konklusjon

Hvorfor et slikt studie?


Hundhammerfjellet (foto: Per-Åge Krogstad)

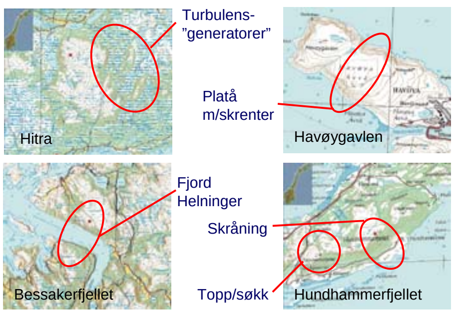
- Komplekst terreng + mange planlagte vindparker i Norge (http://www.industcards.com)
- Posisjonering av turbiner har stor betydning for mulig energiuttak og dynamiske laster
- Vindtunnelforsøk med generisk terrengmodell
- Test case for numeriske modeller

Eksperimentelt oppsett

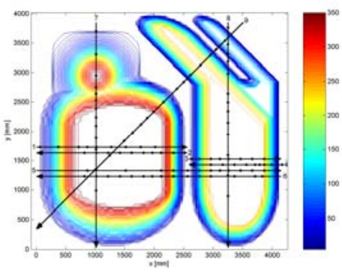


- Simulering av atmosfærisk grensesjikt som over hav
- Laser Doppler Anemometry (LDA)
  - 2 samtidige hastighetskomponenter
  - Vertikale profiler
  - Middelhastighet, Reynoldsspenninger etc.

Terrengmodell – inspirasjon

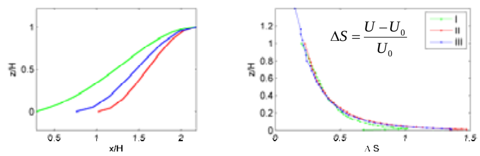


Terrengmodellen og målepunkter



- Generisk
- 4m x 4m x 0.35m
- Skala 1:1000
- Moduler
  - 2D
  - 3D
- 9 ulike terrengvarianter
- Ruhetsvariasjoner

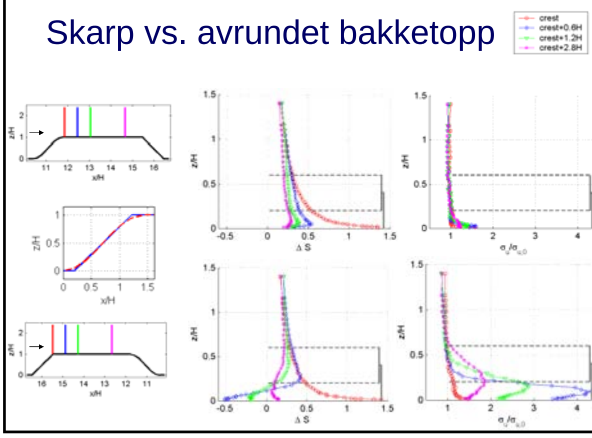
Effekt av bratte bakker



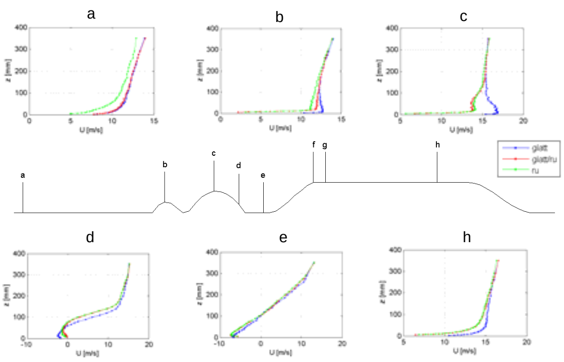
Case	Midlere helning [°]	Maks speed-up
I	27,9	1,0
II	40,7	1,5
III	35,0	1,3

- Speed-up
- Redusert turbulensintensitet
- ➢ Positivt for vindkraft!

Skarp vs. avrundet bakketopp



Ruhetseffekter



Konklusjon

- Mye data og mange terrengvarianter
- Noen effekter presentert, flere funnet
  - Speed-up og redusert TI
  - Separasjon og økte turbulensnivåer (skarp kant, bak fjell, ved foten av fjell)
  - Svært 3D strømning
  - Betydning av ruhet
- ”Generelle” resultater og omfattende test case
- Simuleringer gjort med 3DWind (Ove Undheim)
- Jobber med artikkel og avhandling

Ising på vindturbinene i Nygårdsfjellet vindpark

Phd student: Matthew Homola
Veileder: prof. Per J. Nicklasson

Innhold

- Nygårdsfjellet vindpark
- Ising
- Arbeid hittil
- Resultater
- Videre arbeid

Nygårdsfjellet vindpark

- 3 - 2,3 MW Siemens
- 80 m tårn, 93 m diameter
- 420 moh

- Eiet av Nordkraft Vind
  - (50% Narvik Energi og 50% DONG Energy)

- Konsesjon gitt for trinn 2, men er påklaget
- Inntil 40 MW til, 8-11 stk,

Isingsproblematikken

- Erfaring fra Finland, Sverige, Canada, Sveits, Tyskland
  - Sverige – En turbin stanset i 7 uker
  - Finland – Produksjonstap opptil 30%
- Behov for sammenligning med produksjonsdata fra Norge

- Trenger en bedre måte å estimere ising for vindturbiner

Artikkel om issensorer

ELSEVIER
Available online at www.sciencedirect.com
ScienceDirect
Cold Regions Science and Technology 46 (2006) 125–131
cold regions science and technology
www.elsevier.com/locate/coldregions

Ice sensors for wind turbines

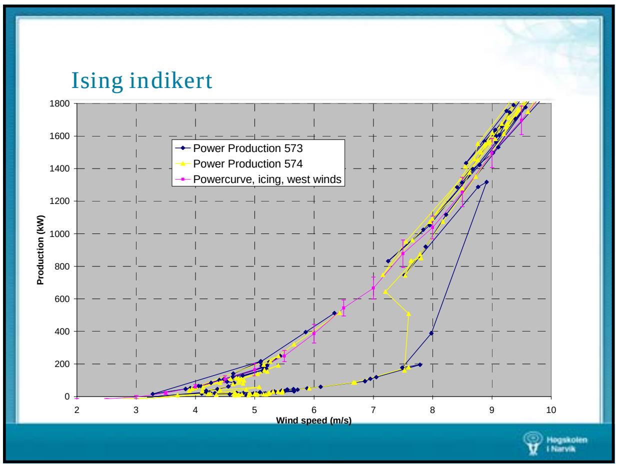
Matthew C. Homola *, Per J. Nicklasson, Per A. Sundsbø
Narvik University College, Box 385, 8505 Narvik, Norway

Received 30 December 2005; accepted 22 June 2006

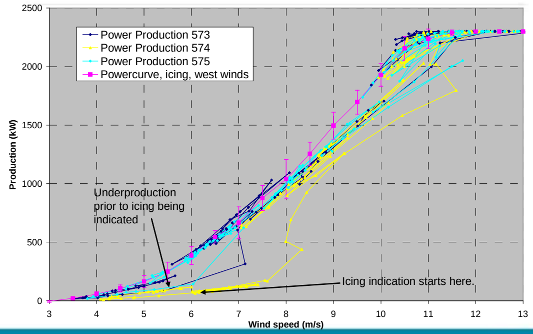
Abstract

A review of ice sensor technology and the challenges for icing detection for wind turbines was performed. A total of 29 different methods for detection of icing were found, and these were then compared with a list of some basic requirements for an icing sensor for wind turbine applications. No reports of ice sensors performing satisfactorily were found, but the sensing methods using infrared spectroscopy through fiber optic cables, a flexible resonating diaphragm, ultrasound from inside the blade or a capacitance, inductance or impedance based sensor seem best suited for wind turbine icing detection.

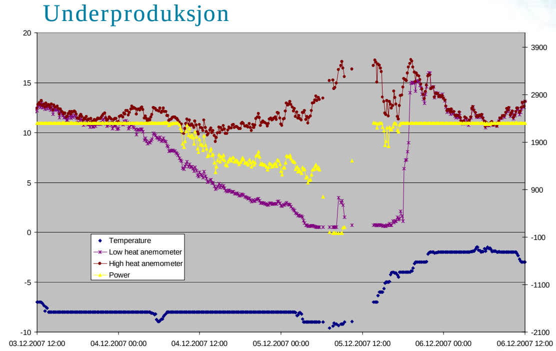

Ising vindtunnel på HiN
Temperatur ned til -30
Vindhastighet opp til 15 m/s
LWC opp til ca. 2 g/m³
Sensor testing i kontrollerte forhold


Ising indikert
Power Production 573
Power Production 574
Powercurve, icing, west winds
Production (kW)
Wind speed (m/s)
0
200
400
600
800
1000
1200
1400
1600
1800
2
3
4
5
6
7
8
9
10

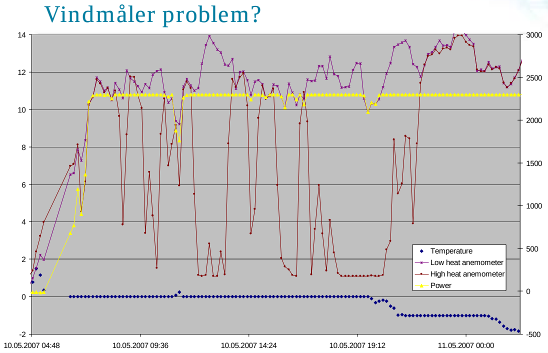
Ising indikert



Underproduksjon



Vindmåler problem?



Noen sluttninger

- Perioder med underproduksjon
- Men, ikke store produksjonstap i 2006
- Ser ut til å ha vært litt mer i 2007
- Underproduksjon har en annen karakter enn forventet
- Usikkerhet med vindmålere

Forprosjekt

- Statoil-Hydro, Nordkraft Vind, Statkraft Development, Høgskolen i Narvik og Kjeller Vindteknikk
- Kvantifisere ising på Nygårdsfjell for en evt. hovedprosjekt

Videre arbeid

- Analyser ferdig data fra 2007
- Usikkerhet med vindmålinger
  - Sonisk anemometer og kamera
- Usikkerhet om ising på blad
  - Kamera
- Videre sensor testing og utvikling
  - Blad montert sensor
- Se på data fra andre vindpark
- Hva med ising på offshore turbiner?
  - Data fra plattformer / helikoptre i arktiske strøk

Kaldtklima forskningssenter ved HiN

Name / position	Topics
Per-Arne Sundsbø Professor	Numerical modelling and simulation of: wind, snowdrift, snow avalanche, icing and Wind Chill Index
Per Johan Nicklasson Professor	Electronics in extreme environments, Sensors for detection of icing
Arne Erik Holdo Professor II at NUC	Computational Fluid Dynamics (CFD)
Lubomir Dechevski Associate professor	CFD, Geometric modelling, Numerical analysis
Børre Bang Associate professor	CFD, Geometric modelling, Computer visualization
Johan Byström Associate professor	Partial Differential Equations, Variational problems
Arne Lakså Associate professor	Geometric modelling, Numerical analysis, Advanced computer programming
Eigil Roaldset Assistant Professor	Energy conservation in Norwegian type wooden house in Northwest Russia
Svein-Erik Sveen Senior Engineer	Frost in ground
Matthew Carl Homola PhD student	Sensors for detection of icing
PhD Student Coventry University/NUC	CFD modelling of icing
Arnt R. Kristoffersen PhD student	Development of simulators
Ph.D. student (from winter-2007)	Permafrost
Ph.D. student (from winter-2007)	Modelling, simulation and evaluation of the effect from Wind Chill Index on outdoor working performance and outdoor working environment

Høgskolen i Narvik

Vind- og iskart for Norge

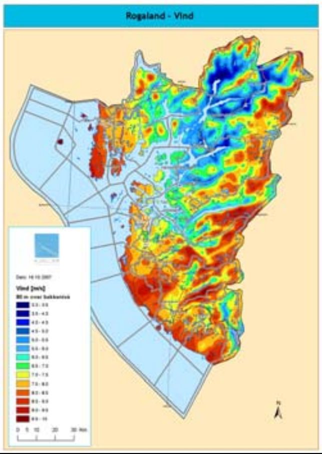
Øyvind Byrkjedal

Innhold

- meso-skala modellering
  - metodikk
  - validering
- Vindkart
- Isingskart
- GIS verktøy

Vindkart for Rogaland:

På oppdrag fra NVE og Rogaland Fylkeskommune



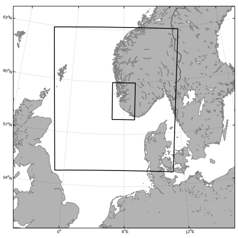
Hva er en mesoskala modell?

- Meteorologisk mesoskala:
  - 1-1000km utstekning
  - Oppløser lavtrykksystem og fronter
- Modell utviklet til bruk i værvarsling (WRF – Weather Research and Forecasting)

Mesoskala modellering

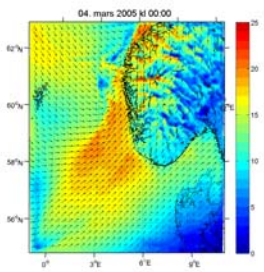
Inngangsdata:

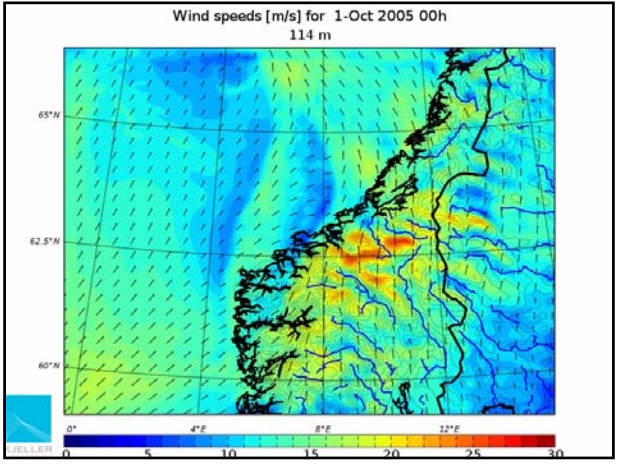
- Vi benytter gitteravstand på 1km x 1km over et modellområde
- Terrengdata (topografi, overflateruhet, snødekke, vegetasjon, bakkefuktighet)
- Meteorologiske storskala analyse data (tas inn i modellen hver 3. time)



Mesoskala modellering

- Vi starter med en initial-tilstand (øyeblikksbilde av atmosfæren), og beregner oss framover i tid fra dette.
- Løser koblede ligninger for vind, temperatur, trykk, vanndamp, nedbør etc.
- Etter at modellen har kjørt en viss tid oppnår vi tisserier på alle mulige atmosfæriske parametere i alle gitterpunkt og i høyder fra bakken og opp til flere 1000m.





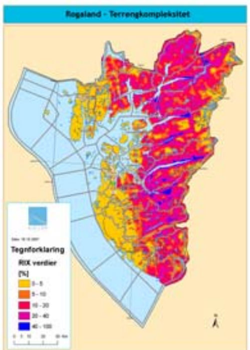
Mesoskala modellering

- Utgangsdata:
  - Tidsserier for vind, temperatur og fuktighet, skydekke for alle gitterpunkt med 1km avstand i flere høydenivåer
- Data fra modellen kan benyttes som inngangsdata til mikroskala modeller som WAsP for å simulere et vindparkområde i større detalj.

Mesoskala modellering

Usikkerheter:

- Usikkerhet knyttet til simuleringen over komplekst terreng
- Begrenset horisontal oppløsning (1km x 1km)
- Krever stor bergnings-kapasitet (enkelte prosesser må forenkles)



Validering av vinddata

- Tidligere validering av vindkartmetodikken (Berge et al., 2007) for tre vindparker i midt-Norge.

Site	WRF deviation (%)	WRF/WAsP RIX-corrected deviation (%)	RIX-value (r=2 km)
1	- 13 %	- 1%	2.0 %
2	- 8 %	0	0.3 %
3	- 9 %	- 1%	0 %
4	- 5 %	0	0 %

Lite komplekst

Site	WRF deviation (%)	WRF/WAsP RIX-corrected deviation (%)	RIX-value (r=2 km)
1	- 3 %	0 %	3.5 %
2	- 8 %	0 %	5.7 %
3	- 3 %	+ 7%	5.1 %

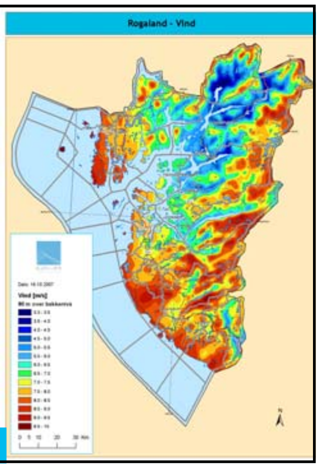
Litt komplekst terreng

Site	WRF deviation (%)	WRF/WAsP RIX-corrected deviation (%)	RIX-value (r=2 km)
1	- 13 %	-1 %	9.9 %
2	- 10 %	-6 %	14.6 %

Komplekst terreng

Avvik årsmiddelvind: 0-13%
Korrelasjon mellom observasjoner og modell: ~0.8

Vindkart for Rogaland:

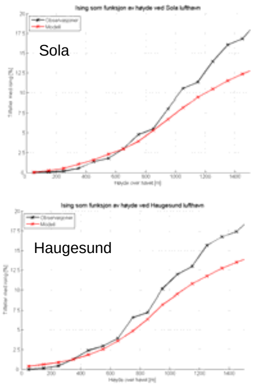


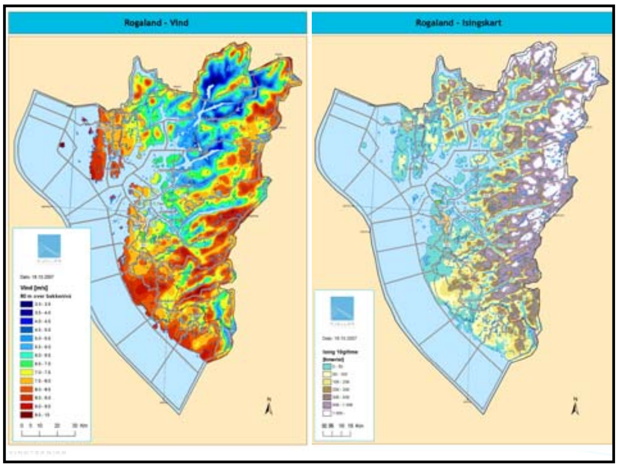
Isingsberegninger

- Ising på vindkraftverk vil redusere kraftproduksjonen
- Benytter data på fuktighet (skyer) og temperatur fra modellen.
- Kan si oss hvor mange timer i året vi kan forvente ising.
- Fortsatt på utviklingsstadiet

Isingsberegninger

- Graden av ising er sterkt avhengig av høyde over havet





GIS verktøy

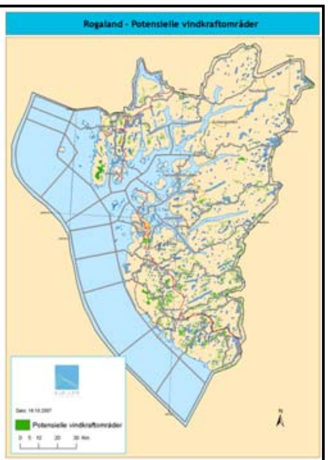
- kombinerer kart over vind og ising med
  - turbulenspotensialet
  - terrengets helning
  - avstand til bebyggelse
- Dette kan brukes til å identifisere potensielle vindkraftområder

Eksempel: potensielle vindkraft-områder

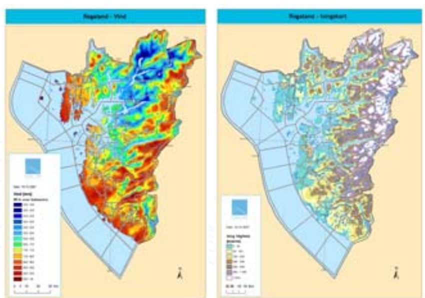
Årsmiddelvind > 7.5 m/s
Helning < 10°

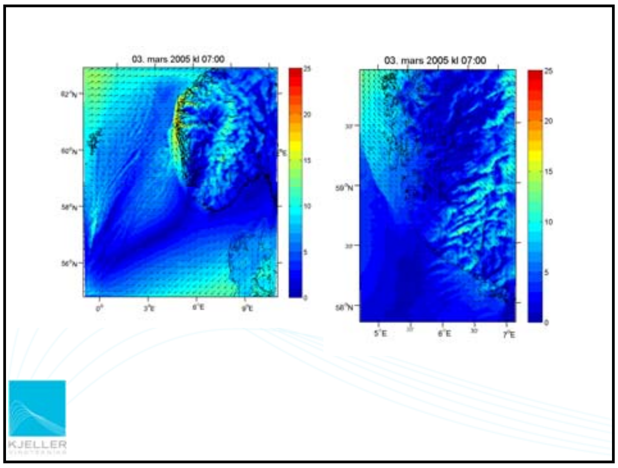
Eksempel: potensielle vindkraft-områder

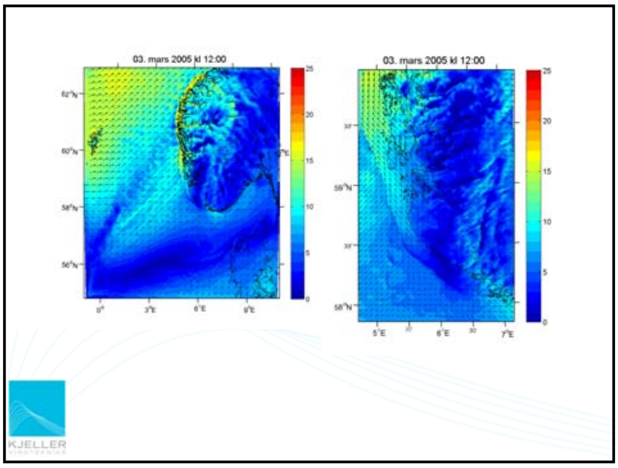
Årsmiddelvind > 7.5 m/s
Helning < 10°
Ising < 10%
Avstand bebyggelse > 1 km

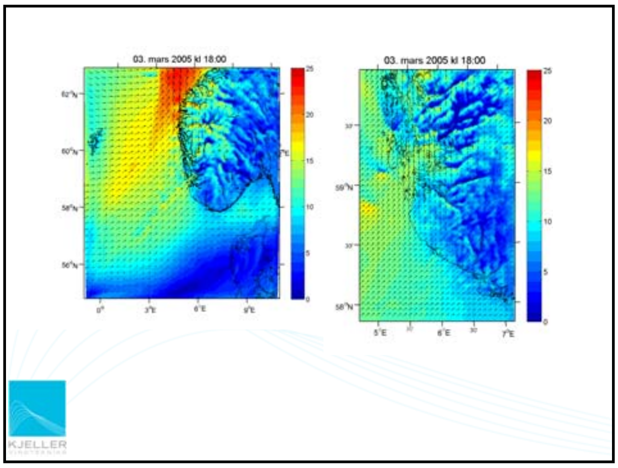


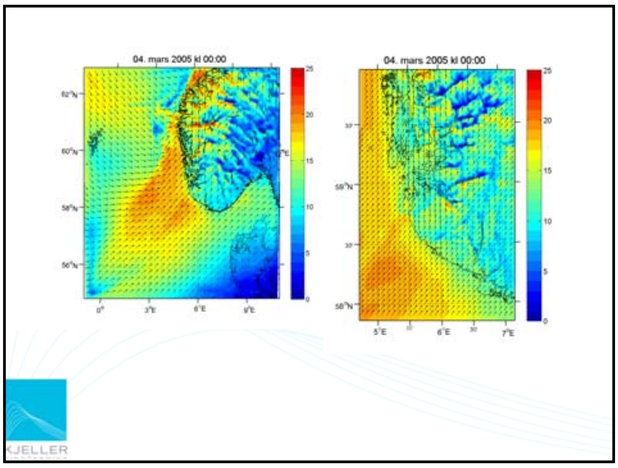
Takk for oppmerksomheten!




03. mars 2005 kl 07:00
03. mars 2005 kl 07:00
KJELLER


03. mars 2005 kl 12:00
03. mars 2005 kl 12:00
KJELLER


03. mars 2005 kl 18:00
03. mars 2005 kl 18:00
KJELLER


04. mars 2005 kl 00:00
04. mars 2005 kl 00:00
KJELLER

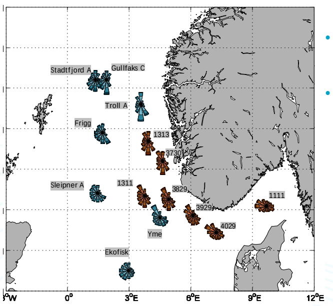
Offshore vindressurskartlegging

Erik Berge
Kjeller Vindteknikk AS

Innhold

- Viktige utfordringer:
  - Langtidsstatistikk: Årsmiddelvind, frekvensfordelinger
  - Vertikalt vindskjær
  - Esktremverdier
  - Turbulens
  - Vaketap
- Metoder og datagrunnlag:
  - Eksisterende måledata og måleteknikker
  - Modelldata
  - Satellittdata

Langtidsstatistikk

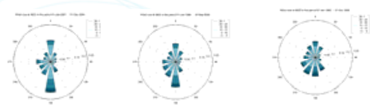


- Observasjoner (plattformer)
- Hindcastdata (1955-2007) 75km*75km ruter

Observasjoner i Nordsjøen

Stasjon	Måleperiode
Ekofisk	11-Jan-1980 22-Apr-2007 ~ 27 år
Frigg	03-Apr-1980 31-Dec-2004 ~ 24 år
Gullfaks C	01-Nov-1989 22-Apr-2007 ~ 18 år
Sleipner A	01-Oct-1993 22-Apr-2007 ~ 14 år
Statfjord A	01-Jan-1980 31-Oct-1989 ~ 19 år
Troll A	01-Apr-1998 22-Apr-2007 ~ 9 år
Yme	01-May-1996 05-May-2001 ~ 6 år

- Årsmiddel fra ~10 m/s (Troll) til ~11.5 m/s (Statfjord) i 100m.



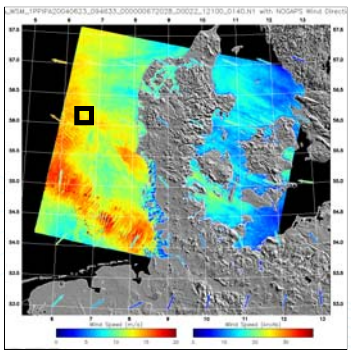
Gullfaks 1 Gullfaks 2 Statfjord

Alternative målemetoder offshore:

SODAR

LIDAR

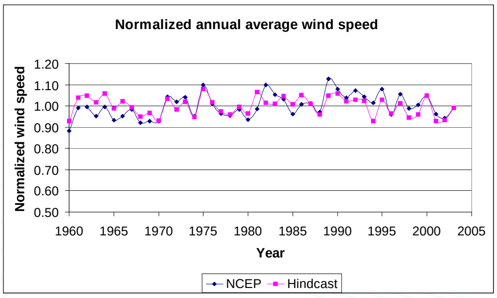
Satellittdata: Charlotte Hasager Risø



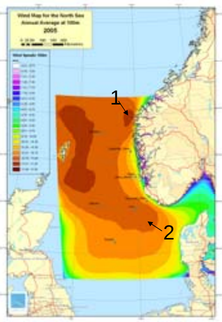
We calculate from radar raw data to satellite wind maps

Envisat ASAR

Modelldata:
(langtidsvariasjon grov oppløsning)



Meso-skala meteorologiske modeller (WRF)
(Årsmiddelvind i 100m for 2005 i 5km ruter)



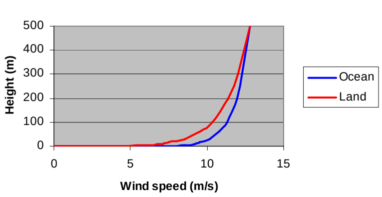
Eksempler fra WRF:

- **1.** Vest for Stadt (~ 35 km)
- **2.** "Lyse" planområde (~ 130 km SV for Lista)

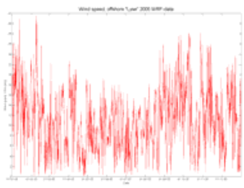
Vindskjær:

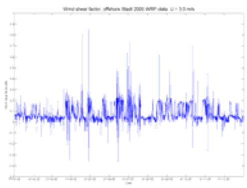
$$\frac{U_2}{U_1} = \left(\frac{Z_2}{Z_1}\right)^{\alpha} \quad \alpha \text{ - vindskjærfaktor}$$

- Verdier av α (50-100m)
  - Hav: < 0.1
  - Fjell med speed-up: < 0.1
  - Flatt jordbruksland: ~ 0.15
  - Skog: > 0.25



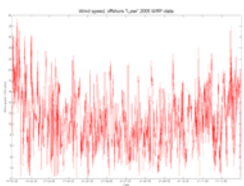
30 km vest for Stadt (2005 WRF):

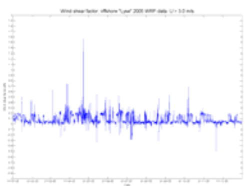




- Årsmiddel 2005 115m: 11.1 m/s
- Midlere α (60-115m): 0.08

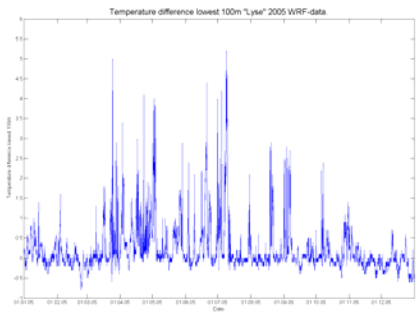
"Lyse offshore" (2005 WRF):





- Årsmiddel 2005 115m: 10.9 m/s
- Midlere α (60-115m): 0.09

Statisk stabilitet (eksempel fra WRF):



Ekstremvind
(10 min.middel i 10m. Harstveit (2005), met.no)

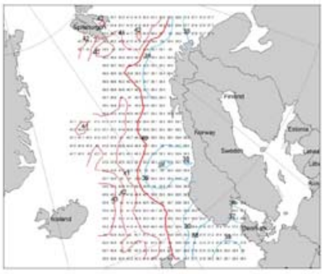
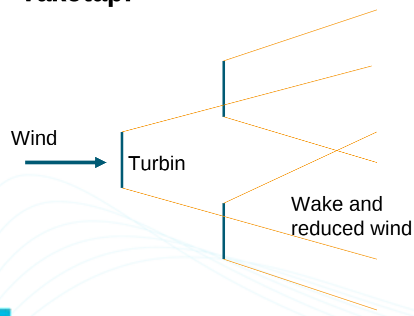


Figure 5
Map of extreme values of 10 minute wind speeds with 50 year return period valid for 10 m above the sea surface, z_0=0.003m

- Ekstremvind i navhøyde 100m?
- Kombinere modeller og målinger

Vaketap:



Offshore vaketap:

- Barthelmie et al. 2007 (Wind Energy):
- Middelgrunden: ca. 10% vaketap i middel
- Tap ~ 80% for turbin 2 når vind langs turbinrekken

Offshore vaketap forts:

- Barthelmie et al. 2006: Vaketap på 10%-20% forventes for store offshore vindparker

Utfordringer innen offshore vind-ressurskartlegging:

- Etablere vindmålinger med høy kvalitet (kostnadene er betydelig større enn på land pr. målepunkt)
- Pålitelige verdier av vertikalt vindskjær (for anvendelse av satellittdata, ekstremvindberegninger etc.)
- Evaluere nytten og nøyaktigheten av modell- og satelittdata
- Bedre forståelse av turbulens, vindskjær og endringer i vindforhold som påvirker turbinene og produksjonen
- Vaketap og frekvensfordelinger for beregning av produksjon

NORSEWInD (North Sea Wind Index Database) EU prosjekt:

- Fokusområder: Irskesjøen, Nordsjøen og Østersjøen
- Skal utnytte (og etablere) offshore vindmålinger (SODAR, LIDAR, Master etc)
- Satelittdata
- Pålitelige verdier av vertikalt vindskjær (for anvendelse av satellittdata, ekstremvindberegninger etc.)
- Modellering av grenselaget over hav
- Numeriske meteorologiske modeller
- Hovedleveranse: Vindatlas Irskesjøen, Nordsjøen og Østersjøen
- Tidsramme: 2008-2012
- Koordinator: Oldbaum Services Limited, UK
- Deltakere: DTU Denmark; DTU RISOE National Laboratories Denmark; DONG Renewables Denmark; Garrad Hassan & Partners UK; INETI Portugal; ISET Germany; Kjeller Vindteknikk Norway; Nautilus Associates UK; Talisman Energy UK; Scottish Enterprise UK; University of Strathclyde UK; WINDTEST Kaiser-Wilhelm-Koog Germany.

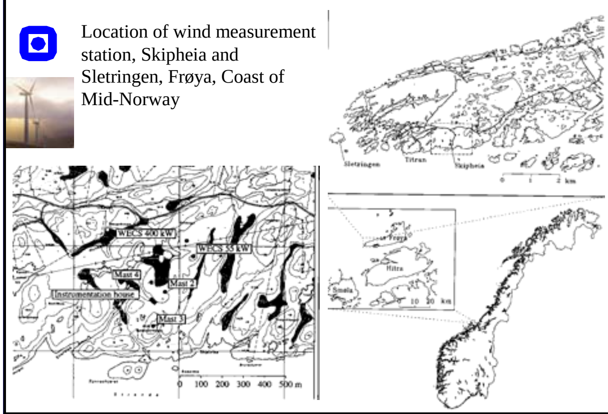
Offshore turbulens -
Erfaringer fra vindmålingene på Frøya

Jørgen Løvseth
Norges teknisk - naturvitenskapelige universitet (NTNU),
Institutt for fysikk, 7491 Trondheim.
Epost: Jorgen,Lovseth@ntnu.no,
Tlf. 7359 1856 / 950 62 134

Contents

- NTNU’s wind measurement station near Titran, Frøya
- Mean wind speed and annual distribution; Four times more energy in winter than in summer
- Height profile
- Turbulence intensity - decrease with height; non Gaussian
- One point turbulence spectra - flat, no gap, f S(f) increase to weather peak
- Two point spectra; coherence, co- & quadrature-spectra, phase
- (Gust factors - non Gaussian distribution)
- IEC 61400-1 (onshore) and -3 offshore specifications (Wind turbines; design requirements) Offshore wind descriptions same as onshore - practically
- Examples of strong fluctuations in the wind speed gradient, in vertical and sideways direction
- Data collection sponsored by Statoil and the main oil companies, results in Norsok standard and NPD guidelines.

Location of wind measurement station, Skipheia and Sletringen, Frøya, Coast of Mid-Norway



Titran, Frøya

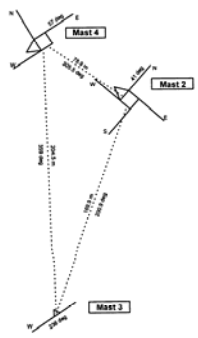
- Top:View towards West from top of 100m mast at Skipheia
- Bottom: View towards East, Skipheia masts, 2 of 100 m with distance 80 m and one of 45 m at distance 200 m (To the very right in the picture). The measurement station visible near the middle mast.
- Sletringen is a small flat islet with rocky surface, West of Frøya, “in the Norwegian Sea”, exposed to undisturbed ocean winds from the western sectors. It has one 45 m mast, equipment located in a near by light-house.

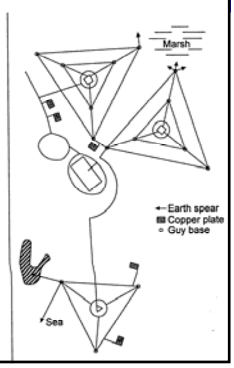
Skipheia, house and one 100 m mast

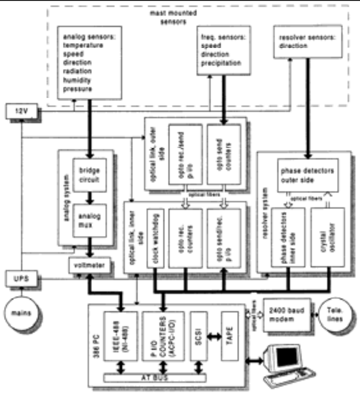
Skipheia , Frøya

Sensors placed pair-wise on slender rods at a distance of 2.5 m from the mast, and on opposite sides. Upwind sensor normally chosen to avoid mast shadow.

To the right: Grounding system







Logging system, Skipheia. Protection against lightening and discharges from atmosphere in signal, power and telephone lines are essential.

Un-interruptible power supply necessary (frequent grid failures in strong wind).

Annual variation of wind at Skipheia

As a function of day number d the wind speed at height z is approximately given by

$$u(z,d) = \bar{u}(z) + a(z)\cos\left[2\pi\,\frac{d+4}{365.25}\right]$$

Height z (m)	10	20	40	70	100
Mean wind speed $\bar{u}(z)$ (m/s)	6.90	7.32	7.82	8.30	8.74
Mean amplitude *a(z)* (m/s)	1.57	1.66	1.76	1.88	1.95

The peak is on 28 December. The peak winter wind energy is approx. 4 times the summer energy. Perfect match for cooperation with hydro power system. Wind is in phase with consumption, and has opposite phase of the hydro system.

Gas power in continuous operation will in the Norwegian system require a storage period of some 6 months at a time when the dams are full; wind energy require only storage for one week at a time when the dams has a low filling.

Height profile – logarithmic & Charnock relation

$$u(z) = u_r\left[1 + \alpha\ln(z/z_r)\right]\ (\equiv \frac{u_*}{\kappa}\ln\frac{z}{z_0})$$

$$\alpha = \left[\ln(\frac{z_r}{z_0})\right]^{-1}$$

$z_0 = (a_{Ch}/g)\, u_*^2$

Fit to data: $a_{Ch} = 0.017$

$\alpha = 0.035 + 0.004\, U_r$

Wind speed u increase with height z due to ground friction, reference height z_r =10m. Charnock relation valid off-shore, stronger waves give increased roughness constant z_0. Over land, z_0 is constant in flat terrain, dependent on ground structure. "Normal" value over land: α = 0.14; at Skipheia, α = 0.10. To first approximation, α is equal to the power law exponent, $u(z) = u_r\,(z/z_r)^{\alpha}$

What is turbulence?

- Turbulence in the wind is defined as deviation from the mean values. Turbulence intensity is the root mean square value of the deviation divided by the mean value of the wind speed. Direct evaluation as

$$I = \frac{\sigma}{\bar{u}} = \frac{\sqrt{\frac{1}{N-1}\sum_{n=1}^{N}[u(t_n)-\bar{u}]^2}}{\frac{1}{N}\sum_{n=1}^{N}u(t_n)}$$

  Normally calculated for a period of ten minutes, sometimes one hour.

- A more complete way of characterising turbulence is through the turbulence spectrum, *S(f)*. The wind speed vector is measured at a frequency normally in the range of 1 to 20 Hz. One hour (or longer) time series of these measurements are Fourier analysed. The mean square of the Fourier coefficient is a measure of the energy in the wind field at the corresponding frequency. On a logarithmic scale, f·S(f) is plotted to give the correct visual impression of the energy distribution. It follows

$$\sigma^2 = \int_{f_n}^{f_x} S(f)\,df$$

Turbulence intensity in IEC 61400-1 Ed.3

61400-1 is WIND TURBINES design requirement for land based turbines, but the wind description is taken to be the same for off-shore turbines as well.

The reference value I_{ref} is the mean value defined for V_{hub} = 15 m/s and 90-percentile value of σ.

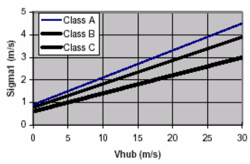
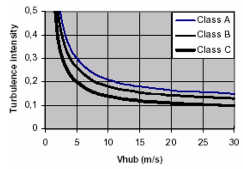


Table 1 - Basic parameters for wind turbine classes[1]

Wind Turbine Class		I	II	III	S
V_{ref}	(m/s)	50	42,5	37.5	Values
A	I_{ref} (-)	0,16			Specified
B	I_{ref} (-)	0,14			by the
C	I_{ref} (-)	0,12			Designer



Turbulence intensity u > 10 m/s Frøya

Integrated spectrum:

$$I(z) = \frac{\sigma(z)}{u(z)} = 0.13\left(\frac{u_r}{u_0}\right)^{0.38}\left(\frac{z}{z_r}\right)^{-0.22}$$

u_0 = 20 m/s, z_r = 10 m

Fit to 1 h time series (0.86 hz detrended measurements)

$$I(z) = 0.085\left[\frac{z}{z_r}\right]^{-0.22} + 0.002u_r$$

Turbulence intensity is the ratio between the standard deviation and the mean wind speed. In maritime conditions, it normally decreases up to 7 m/s and then starts increasing. The above model is valid for u > 10 m/s. The decrease with height is twice the "standard" rate.

Atmospheric stability

Neutral: Small thermal forcing

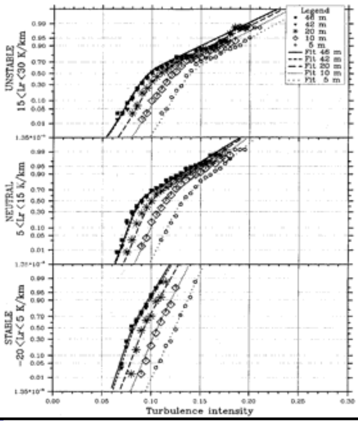
Unstable: Thermal gradient more negative than for neutral, give thermal turbulence.

Stable: Reduction of turbulence.

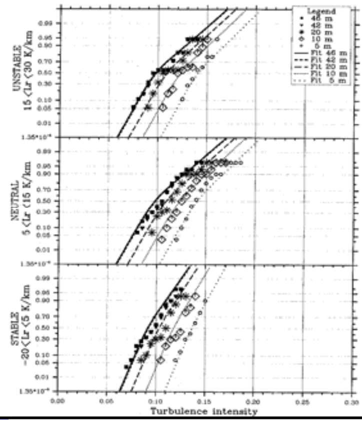
Normal plot of turbulence intensity for 1 h periods, u = 14-18 m/s

$I(z) = \sigma(z)/U(z)_{run.ave.}$

Gaussian dependence will give straight lines. Increasing non-Gaussian effect for unstable atmospheric conditions (cold air on warm ocean)



Normal plot of turbulence intensity 18 - 22 m/s. Compared to last slide, we see more "normal" behaviour for higher wind speeds.



Traditional onshore turbulence picture

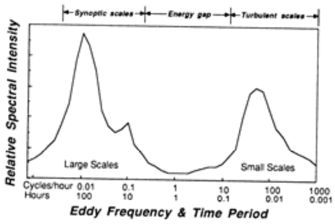
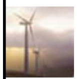
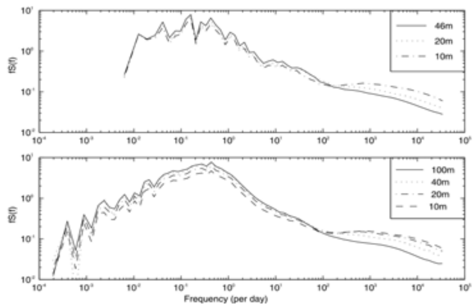


Fig. 2.2 Schematic spectrum of wind speed near the ground estimated from a study of Van der Hoven (1957).

- Energy gap between "Weather variations" and "Turbulence". Turbulence traditionally limited to periods less that 1 hour. Not much difference in energy in a range from 1 hour and down compared to 10 minutes and down, the exact frequency range for defining turbulence intensity not very important onshore. Picture copied from Stull: An Intro. to Boundary Layer Meteorology

Long term spectra (14 years & 160 days) Frøya





Turbulence power spectra versus frequency. Top: Sletringen data, bottom: Skipheia. The peak region indicates weather periods of 2 to 5 days. For highest sensor there is no indication of a dip for one hour periods, but it may be noticed in spectra for high wind speed. Generally a change of slope corresponding to period of 10 minutes (frequency 150 per day). Notice intensity cross-over at 15 min periods (100/d)

High frequency spectra

$$f \cdot S(f) = A(u_r, z)\gamma / \left[1 + \tfrac{3}{2}\gamma^n\right]^{\frac{5}{3n}}$$

$$A(u_r, z) = 0.074 u_r^2 \left(\frac{u_r}{u_0}\right)^{0.75} \left(\frac{z}{z_r}\right)^{-0.22}$$

$$\gamma = f / f_x \qquad f_x = 0.0232 Hz \left(\frac{u_r}{u_0}\right)^{0.75} \left(\frac{z}{z_r}\right)^{-0.68}$$

$$n = 0.47 \quad u_0 = 20 m/s \quad u_r = u(z_r) > 10 m/s$$

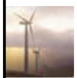
f_x is frequency for maximum of $f\,S(f)$

u_r = 10 m is reference height

High frequency: f > 0.3 mHz. Spectra give the distribution of turbulent energy versus frequency. The "standard" spectrum has n = 1 (or n 2); the exponents on the ()'of *A* are both zero, for f_x : 1 and -1, respectively. Thus "our" spectrum indicates a flatter distribution, sharper increase with wind speed, and a decrease with height not seen normally. Approximately the same both at Sletringen and Skipheia in maritime sector.

Flat Frøya spectrum

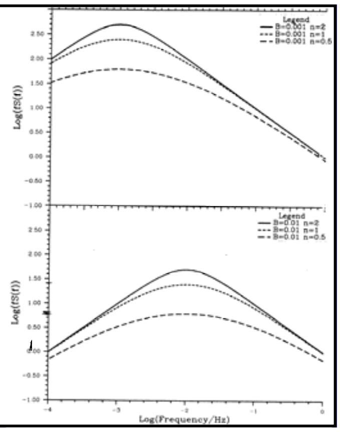
compared to alternatives



Model spectrum

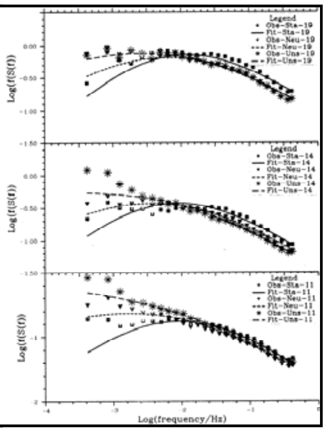
$$f \cdot S(f) = \frac{f \cdot A}{(B^n + f^n)^{5/3n}}$$

- For two different peak frequencies
- From top
  Harris spectrum: n=2 Full line
  Kaimal spectrum: n=1 Short dash
  "Frøya" spectrum: n=1/2 Long dash
- Ratio between peak values with same asymptotes:
  Factor 2, Harris - Kaimal
  Factor 4, Kaimal "Frøya"

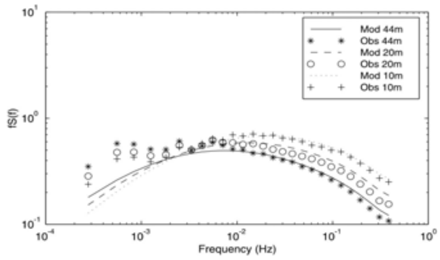


Sletringen spectra Maritime sector

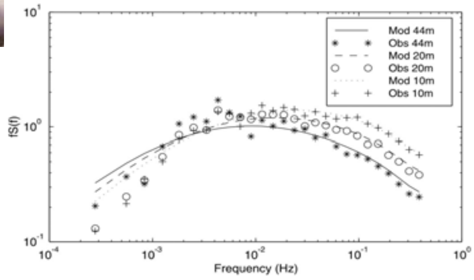
- 3 wind speed classes, mean values of which are indicated
- 3 stability regimes: Stable, Neutral and Unstable.
- One hour base period, 0.85 Hz logging frequency, 0.43 Hz



Sletringen spectra 15 - 20 m/s, independent data (Åse Kjellevold)



Sletringen Spectra 20 - 25 m/s, independent data (Åse Kjellevold)



Two point spectra or coherence

The coherence is a measure of the correlation between the squared Fourier-components of two time series. The coherence (also called coherence squared in some books) and phase angle φ are defined as

$$coh(f) = \frac{C(f)^2 + Q(f)^2}{S_1 S_2} \qquad \tan(\varphi(f)) = -\frac{Q(f)}{C(f)}$$

Here, C is the co-spectrum and Q the quadrature spectrum (real and imaginary part of the cross spectrum) and S_1, S_2 are the spectral densities for the respective time series.
The traditional Davenport formulation of coherence.

$$coh(f) = \exp(-afd/u)$$

where d is the distance between the points of observation, has been re-formulated to allow different damping coefficients in the three directions (x-axis along the wind direction, y- lateral and z-direction vertical).

Two point spectra or coherence - cont

$$coh(f) = \exp\left[-\frac{f}{u_r}\{(a_x\Delta x)^2 + (a_y\Delta y)^2 + (a_z|\Delta z|^{(1+q)})^2\}^{1/2}\right]$$

$$a_i = \alpha_i \cdot f^{-r_i} \cdot z_g^{-p_i} \qquad z_g = \sqrt{z_1 z_2}/z_r \qquad z_r = 10\text{ m}$$

The parameters and the exponents were determined by a least square fit to the 3 masts experimental data. The values shown in Table 2 correspond to those given in the NPD guidelines

Direction (relative to wind)	α_i	r_i	p_i	q
x (parallel)	2.9	0.08	0.4	-
y (lateral)	45	0.08	0.4	-
z (vertical)	13	0.15	0.5	0.25

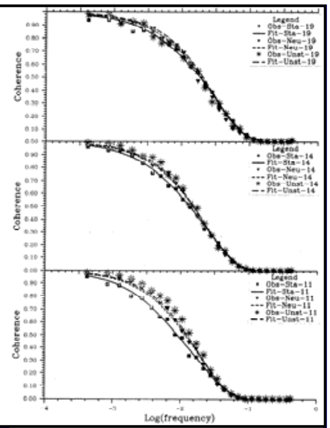
IEC 61400-1 specify the same damping for vertical and lateral separation, and no damping for parallel separation. Agrees approximately for vertical direction - but no dependence on geometrical height or q.

Vertical coherence Sletringen 46 -20 m

- Comparisons theory - experiment
- 3 wind speed classes > 10 m/s, median value indicated
- 3 atmospheric stability classes; stable, neutral and unstable.
- For high wind case, coherence length for coh = 0.5 at f = 0.02 Hz T = 50 s

$$\lambda_z = \frac{u_r}{f \cdot a_z} \approx 38\,m$$

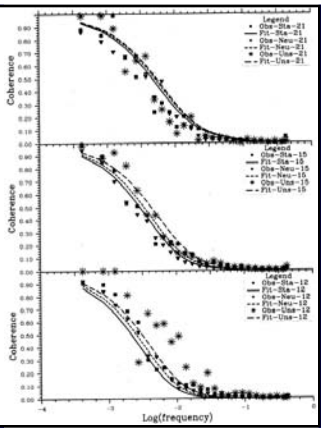
For larger frequencies, the correlation decreases further.

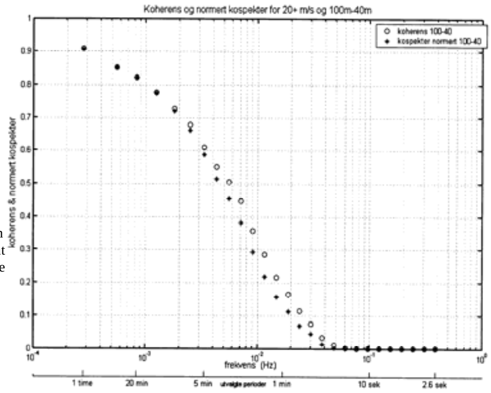


Lateral coherence, Skipheia

Coherence model from fit to 3 mast data compared to data in 30º normal to plane through 100 m masts, distance 79 m (few data).

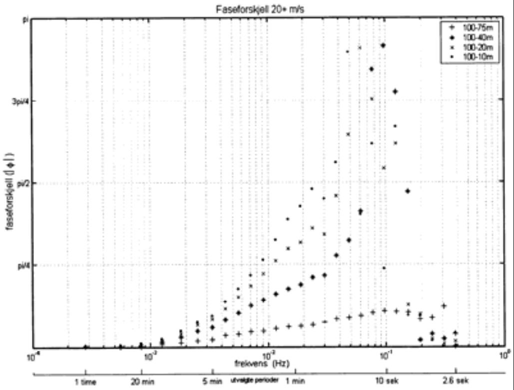
- 3 wind speed classes > 10 m/s, median value indicated
- 3 atmospheric stability classes; stable, neutral and unstable.
- For high wind case, coherence coh = 0.5 at f = 0.005 Hz, T = 200 s, Δy = 79 m
- For higher frequencies or longer periods, there is less coherence between the masts, or over the rotor of a large wind turbine.





Data from Hogne N. Larsen
Co-spectra gives correlation between wind components at the same time in the vertical column (phase dependent)

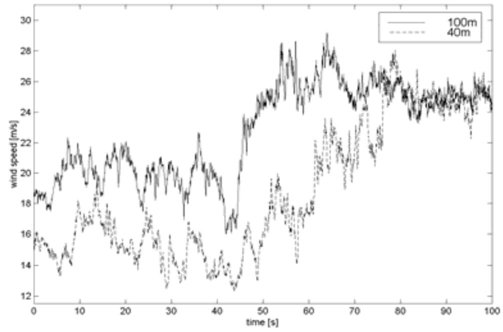
Phase difference between wind components at different heights (Hogne N. Larsen)



Wind gusts at higher levels are in front of those below. Notice nearly opposite phase for f=0.1 Hz at 10 and 100m.

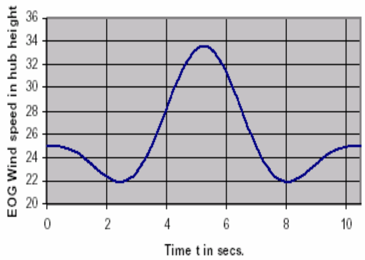
In time domain this means half a period or 5 s. 20/100 has a delay of 12 s at 10 mHz.

Example of vicious height gradient; 20 Hz time seies (Michal Koziel).



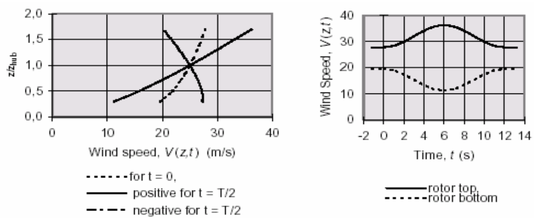
Discrete gusts in IEC 6400-1

- We have not search for this shape of gusts, but examples of time series show similar phenomena. The extension of the accelerated jet will be important



Wind shear fluctuations - IEC 6400-1 Ed.3

- A specific example of the IEC extreme wind shear is shown below. For the negative case, the top & bottom speed fluctuations negated.. Examples later show similar fluctuations.



Gust factors

- In the NASA standard, gust factors are defined, and the oil companies also wanted establish experimental data for this quantity. It is conventionally defined as the ratio between the maximal mean value over a (short) sub-period τ to the mean value in the period being analysed, e.g. 1h. Running average wind speed at 10 m height was actually chosen as normalising quantity, calculated in a 1 hour symmetric window around the maximum gust.

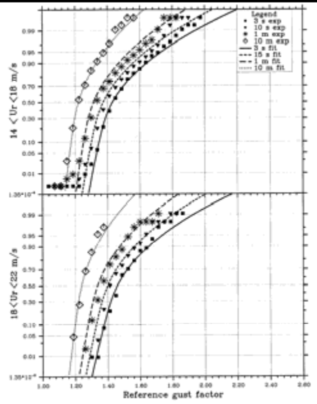
$$G_r(z,\tau) = \frac{Max < u(z) >_{\tau}}{< u(z_r) >_{T;ra}}$$

Values for one hour intervals are shown next page in a normal plot; which means that normally distributed values fall on a straight line. One will observe that the deviation from Gaussian distribution is quite strong, but is reduced with increasing wind speed. The deviation is generally stronger for thermally unstable conditions.

The numerical model is quite complicated.

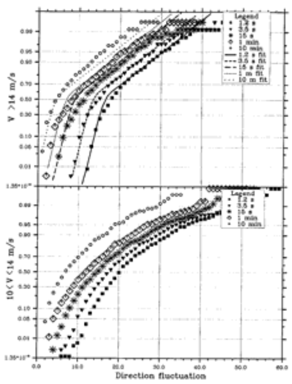
Gust factors, wind speed

- Normal plot of gust factors at 46 m height from Sletringen for one hour periods. Mean value increase slightly with wind speed, non Gaussian character decrease with wind speed.



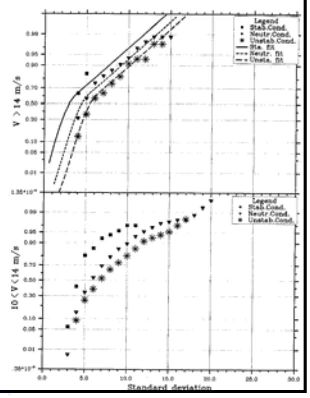
Direction fluctuations

- Normal plot of direction gust relative to running average, or maximum direction deviation over sub-periods from the running average value over one hour periods. Reference to running average will eliminate effect of linear trend in the data.
- 45 m height, Sletringen



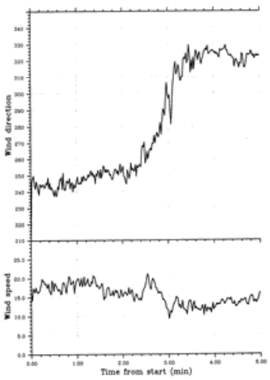
Direction standard deviation

- Normal plot of standard deviation relative to running average for two speed classes, 45 m height, Sletringen
- Data are shown for three stability classes



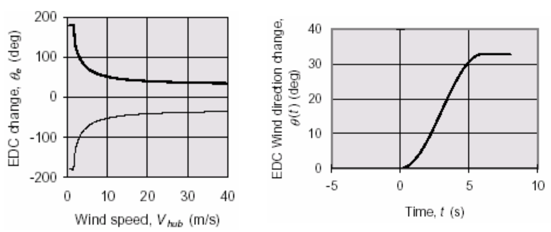
Direction time series

- Time series plot showing a change of direction of some 85º over 80 sec, and 40º over 6 sec.
- 45 m height, Sletringen

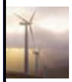


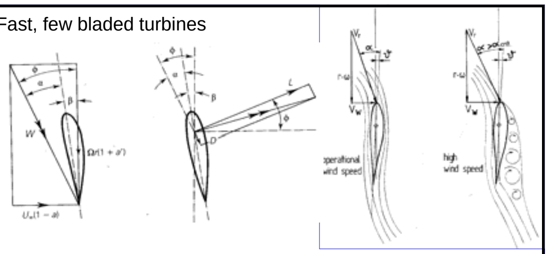
Extreme direction change in IEC 6400-1 Ed.3

Magnitude versus wind speed and time dependence of extreme wind direction change according to IEC. Such a rapid direction change is probably rather local, and the relevance may be questioned.



Fast, few bladed turbines



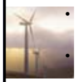


•For most of the blade span, the in-plane velocity Ωr (Ω is angular velocity, assume a'=0 in Fig), is much larger than the incoming wind velocity u0 (=uoo in the Fig). The resulting wind relative to the blade is w. The positive torque contribution from an wing section at radius r will be proportional to

$$q = L\sin\phi - D\cos\phi = \tfrac{1}{2}c\rho w^2\left[C_L(\alpha)\sin\phi - C_D(\alpha)\cos\phi\right] \qquad \alpha \ll 1 \text{ and } \phi \ll 1: \quad q \approx k w^2 \phi (\alpha - \alpha_0)$$

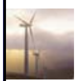
- The lift force L and the drag force D is indicated in the left Fig. c is the cord length (width of the wing), C_L is the lift coefficient normally proportional to the attack angle α. C_D is normally small for small α. For $\alpha > \alpha_{crit}$ (right sketch) the lift disappear due to turbulence - stall. Since α increase with u_0 , this can be used to control production. The alternative is "pitch" control, adjusting β to a suitable value. Note that ϕ also increase with u_0

Correlations in the wind field important for turbine lifetime



- The Danes have experienced that periods of wind speed over 20 m/s represent the greatest wear on turbines.
- At 25 m/s, the turbine plain wind velocity is approx. 3 times that at rated wind speed, making the relative lift component in turbine plane larger by a factor 3 and the attack angle 1/3 of value at rated, which means that the system is sensitive to wind speed fluctuations. The most important source is the spatially differences in the wind field seen by the rotating blade. Extreme cases may mean negative torque in low position, 3 times normal torque in upper position. Solution: Continuous independent pitching of blades, at least for wind speeds above 20 m/s, to decrease fatigue and increase life time.
- Thus transversal correlation in the wind field is important. Since the phenomena are non-Gaussian, discrete time and spatial histories are important. Therefore, a measurement station like Skipheia is important, with several masts and the recording of complete time series with Hz or even 20 Hz frequency in spatially different locations.

Conclusions



- There are significant differences in typical features between land and ocean wind.
- Turbulence off shore increase with wind speed above 10 m/s, but decreases with height.
- Low correlation in transversal directions. More advanced control could reduce fatigue loading on turbine and transmission.

Nettintegrasjon

SmartGenerator – utvikling av ny generatorteknologi for vindkraftverk,
Prof. Robert Nilssen, NTNU

Kabelteknologi for offshore vindkraft, Vegar Syrtveit Larsen,
Nexans Norway

HVDC Light for tilkobling av offshore vindparker, Peter Sandeberg,
ABB Grid System, Sverige

Bruk av vannkraft til balansering av store mengder offshore vindkraft, forsker
Thomas Trötscher, SINTEF Energiforskning

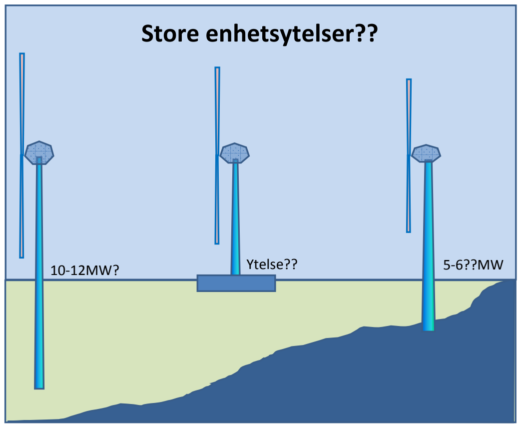
Modellering av variabel hastighet vindturbiner for kraftsystemanalyse,
PhD student Jarle Eek, NTNU

Systemkrav til vindkraftverk, seniorforsker John Olav Tande,
SINTEF Energiforskning AS

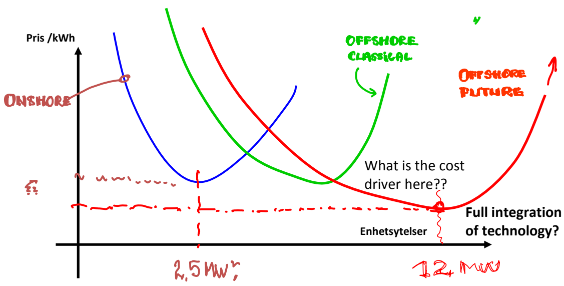
Konklusjoner!!?

- Ny teknologi er testet og verifisert. Mål oppnådd.
- SmartMotor og Wärtsilä kan og ønsker å lage store norske demonstratorer nå !!
- Stor industriell satsing må til!
- Vi har mye kompetanse allerede. Husk utvikling, ikke bare forskning. Start løpene nå. IPR er viktig.
- Samarbeid om maskindesign, komposittmaterialer, korrosjon, kjøling, høyere spenninger, instrumentering av demonstratoranlegg, styring
- INTEGRASJON opp mot en norsk eller utenlands TURBINLEVERANDØR nå!

Store enhetsytelser??



Pristendenser

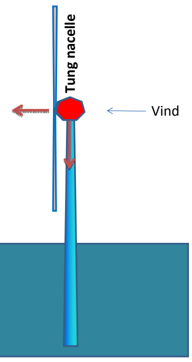


Strikkepinne med en møllestein på toppen!

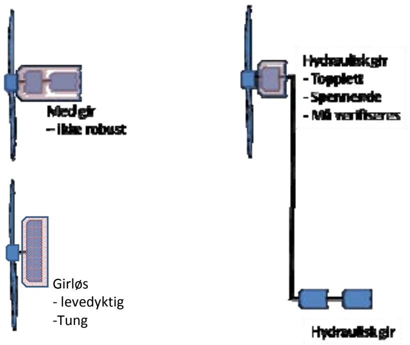
Maksimalvindtrykk – 100 – 500t??

Maksimalt akseptabel nacellevekt 350t?
3MW - ca 200t - Tradisjonell PM generator 80t
5MW - ca 350t?
10MW Umulig - Med dagens teknologi!!

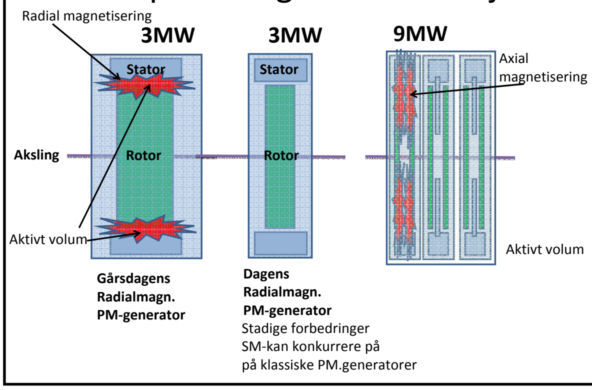
Målet må likevel bli:
12 MW som veier maks. 350t!!?



Nacellekonsepter
- hva blir fremtidens løsning?

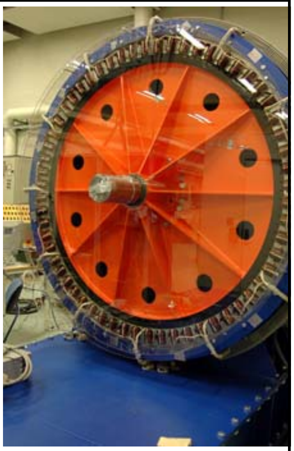


Kompaktering - vektreduksjon

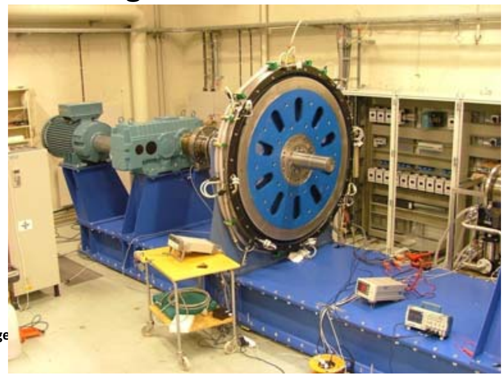


Testmodell radial er bygget

- nye viklingskonsepter for svært høypolte maskiner

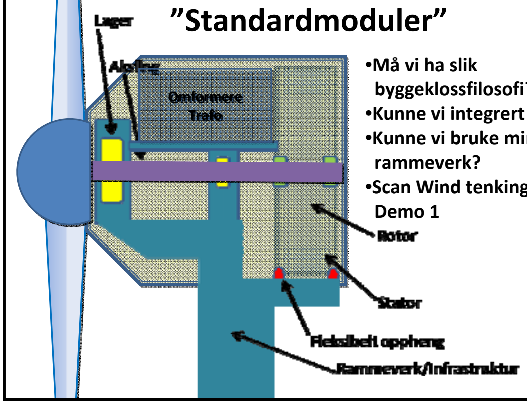


AFPM – Også testet – svært lovende



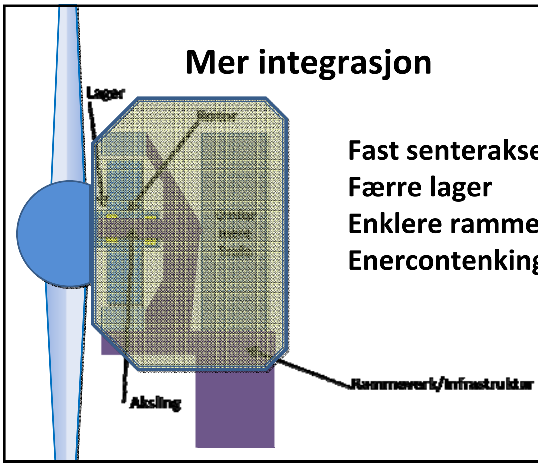
Bygge

Sammenstilling av "Standardmoduler"



- Må vi ha slik byggeklossfilosofi?
- Kunne vi integrert mer?
- Kunne vi bruke mindre rammeverk?
- Scan Wind tenking på Demo 1

Mer integrasjon



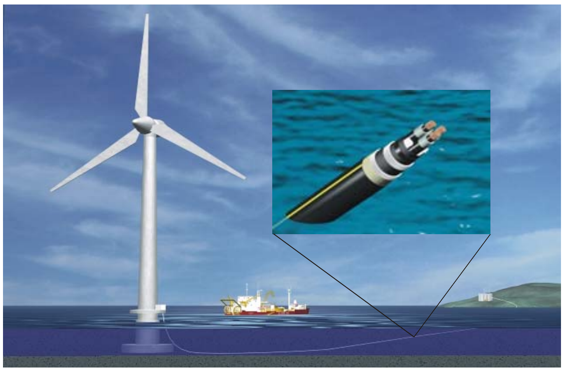
Fast senterakse
Færre lager
Enklere rammeverk
Enercontenking

Nexans — Kabelteknologi for offshore vindkraft

Vegar Syrtveit Larsen
Nexans Norway

1

Nexans — Kabelteknologi for offshore vindkraft



2

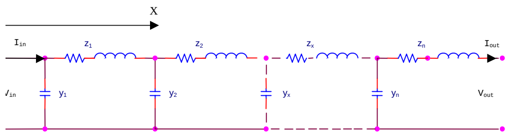
Nexans — Kabelteknologi for offshore vindkraft

- Avgjørende parametere for kabeldesign
  - Overføringskapasitet
  - Lengde fra land
  - Spenningsnivå
  - Statisk vs. dynamisk

3

Nexans — Kabelteknologi for offshore vindkraft

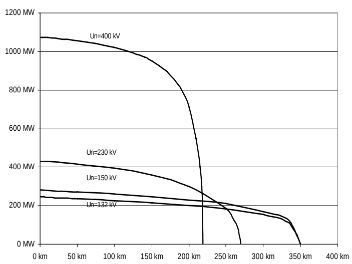
- Avgjørende parametere for kabeldesign
  - Kabelen har høy kapasitans og lav impedans
  - Lange kabler må modelleres med distribuerte parametere



4

Nexans — Kabelteknologi for offshore vindkraft

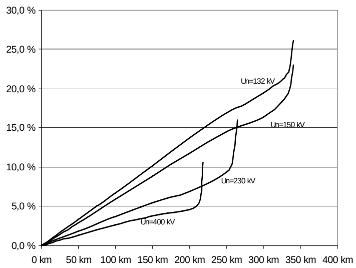
- Overføringskapasitet vs. lengde
  - ± 10% spenningsvariasjon mellom null og full last
  - Tap maks. 10%
  - Gravedyp 1 m
  - Temp. 10°C



5

Nexans — Kabelteknologi for offshore vindkraft

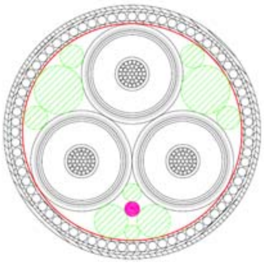
- Overføringstap vs. lengde
  - 230 kV, 7.5% at 200km
  - 400 kV, 3% at 100km



6

Kabelteknologi for offshore vindkraft

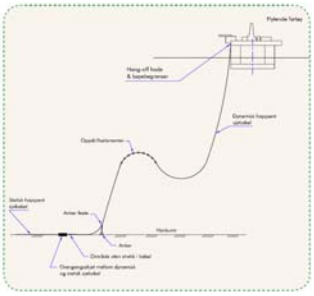
- Statiske kabler
  - Velkjent og utprøvd teknologi
  - Kabler, FO-element og utstyr
  - 420kV 1-leder PEX-kabler og utstyr
  - 170kV 3-leder PEX-kabler og utstyr



7

Kabelteknologi for offshore vindkraft

- Dynamiske kabler
  - Utmatting
  - Radiell vannbarriere (≥52kV)
  - Avhenging



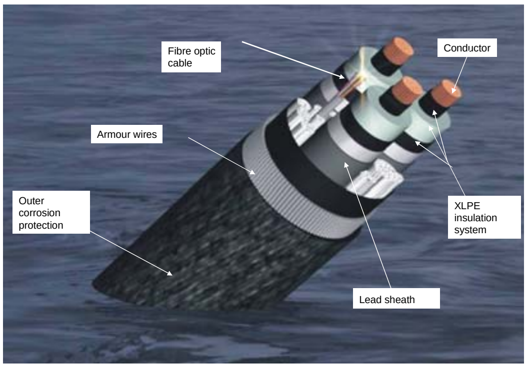
8

Kabelteknologi for offshore vindkraft

- Radiell vannbarriere
  - For spenninger over 36kV
  - Kun metaller er diffusjonstette
  - Eliminerer aldringsmekanismen vanntrær i isolasjonen

9

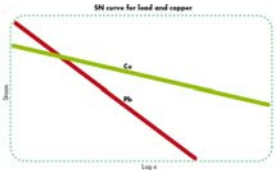
Kabelteknologi for offshore vindkraft



10

Kabelteknologi for offshore vindkraft

- Radiell vannbarriere
  - Konvensjonell design med blykappe
  - Kobberbånd med overlapp
  - Langsgående sveiset kobberbånd
  - Ekstruderte polymermaterialer



11

Kabelteknologi for offshore vindkraft

12

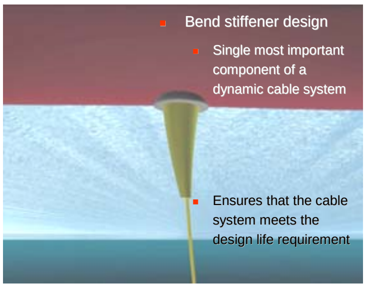
Kabelteknologi for offshore vindkraft

- Utmatting
  - Kobber har bedre utmattingsegenskaper enn bly
  - Omfattende dynamiske beregninger
    - SN-kurver
    - Beregningsverktøy
    - Input parametere (bevegelsesmønster, konfigurasjon etc)
  - Tverrsnittsanalyse
    - UFLEX
    - Utmattingsanalyse
  - Fullskalaforsøk
    - Testrigg for simulering av 30-50 års levetid

13

Kabelteknologi for offshore vindkraft

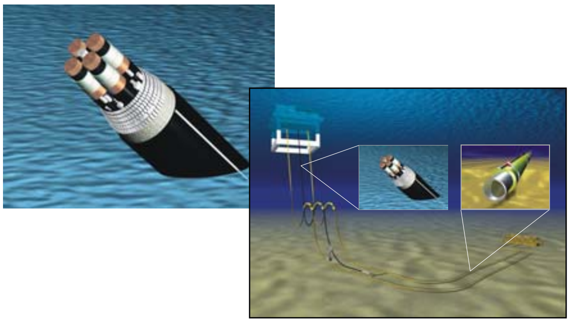
- Avhenging
  - Hang-off
  - Bøyestiver
  - Oppdriftselementer



14

Kabelteknologi for offshore vindkraft

- Dynamiske kabler



15

HVDC Light to Support Integration of Offshore Wind Power

Peter Sandeberg
ABB Grid Systems
Trondheim 2008.01.25

ABB

HVDC Technologies

HVDC Classic 300 – 3000 MW

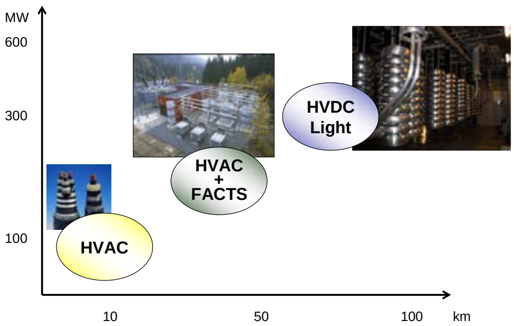
- Thyristor controlled
- Switched Reactive Power Control
- Typical design valve building plus switchyard
- Mass impregnated cables

HVDC Light 50 – 1100 MW

- Transistor (IGBT) controlled
- Continuous Voltage and Reactive Power Control
- Typical design with all equipment (including transformers) in compact building
- Extruded cables

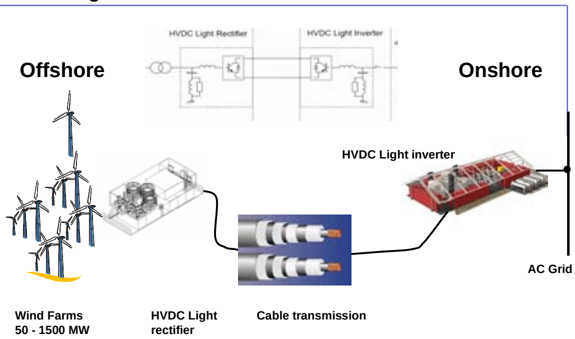
ABB

Grid Connection for wind



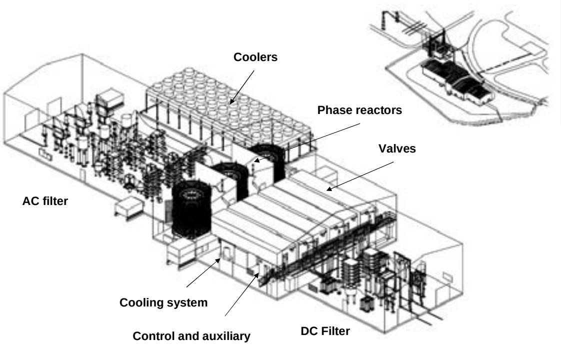
ABB

HVDC Light for Grid Connection of Wind Farms



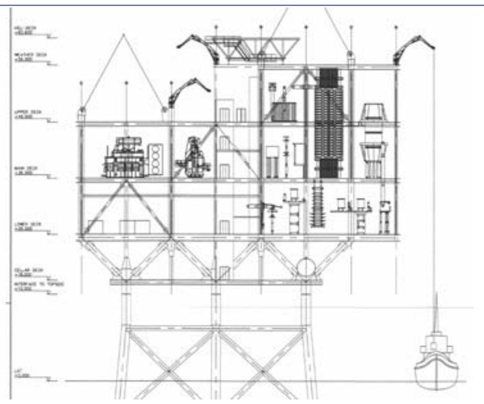
ABB

HVDC Light , ±150 kV, 175- 555 MW



ABB

1100 MW offshore module

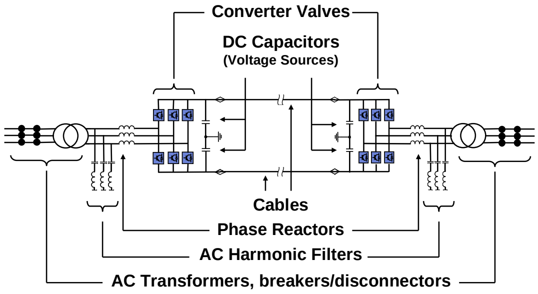


Connecting wind farms by HVDC Light® - Customer Values

- Grid management
  - Full grid code compliance
  - Superior controllability
  - Voltage and reactive power control
  - Loss reduction in connected AC network
  - Support connections at weak network points
  - Passive Load Operation (Black Start)
- Environmentally adapted
  - Underground /Submarine transmission
  - Small footprint and low profile of converters
  - Oil free cable
  - Low emissions of electrical and audible noise
- Proven offshore concept
- Flexible modular design
  - Short implementation time
  - Wide range of power

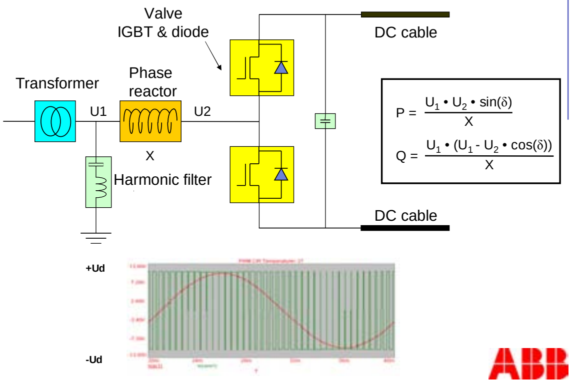
ABB

HVDC Light® – Simplified Single Line Diagram



ABB

HVDC Light

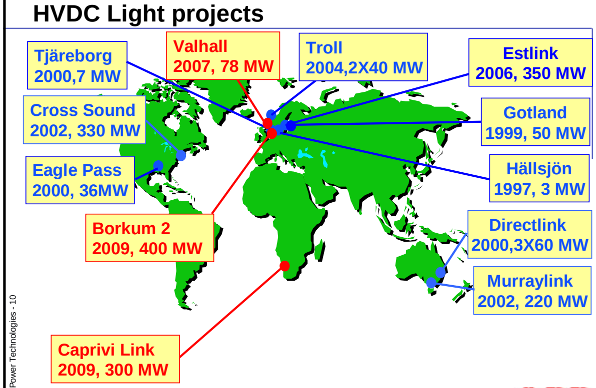


$$P = \frac{U_1 \cdot U_2 \cdot \sin(\delta)}{X}$$

$$Q = \frac{U_1 \cdot (U_1 - U_2 \cdot \cos(\delta))}{X}$$

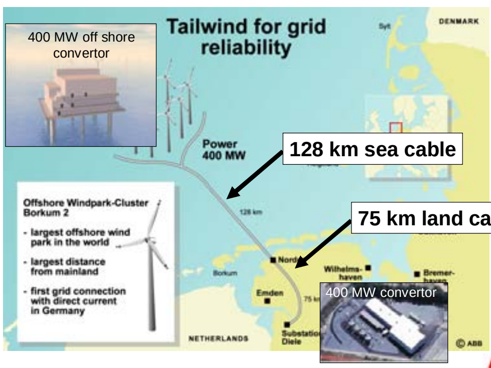
ABB

HVDC Light projects



ABB

EON Netz, Borkum 2, 400 MW HVDC Light



ABB

Conclusions

Suitable technologies for grid connection can offer wind power:

- Location on best wind sites
- Access to the market
- Simplified grid code compliance and support by
  - Reactive power control
  - Ability to assist network with voltage control
  - Frequency tolerance
  - Capability to ride through faults

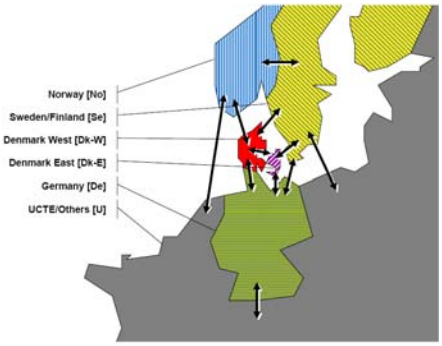
Power and productivity
for a better world™

I: Using hydro power to balance large amounts of offshore wind power

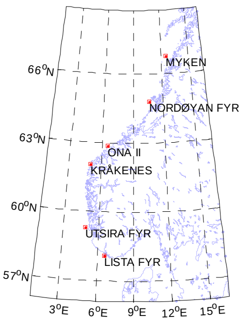
II: Designing optimal offshore grids

Thomas Trötscher, Magnus Korpås, John Olav Giæver Tande
SINTEF Energy Research
Thomas.Troetscher@sintef.no

Power market model

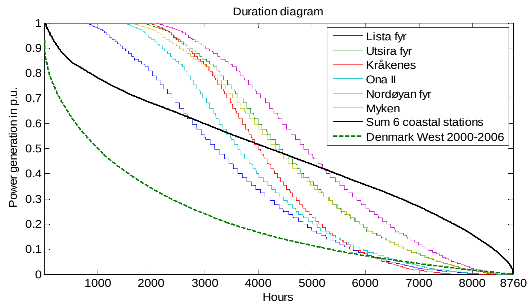


Wind data



- Wind data from coastal stations along the Norwegian cost
- Long measurement history
- High mean wind velocity
- Similar to wind velocities encountered offshore
- Hourly values, 21 consecutive years

Wind data

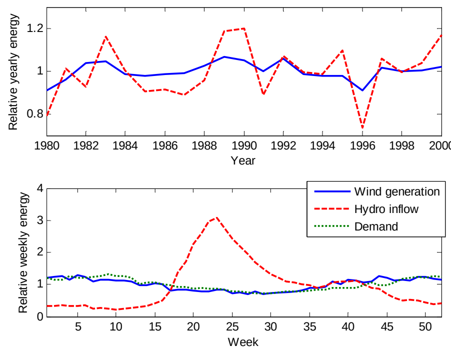


Simulation study

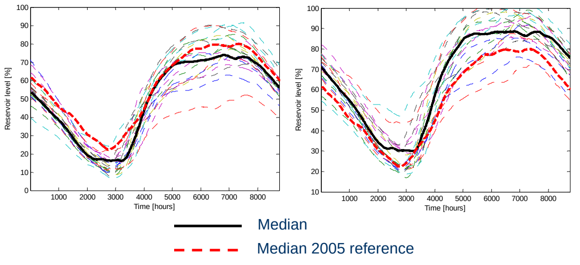
5 simulation cases describing possible situations in 2025:

- A: 10 TWh load increase (120 TWh today)
- B: …added 25+10 TWh offshore+onshore wind (5.5 + 3.1 GW)
- C: …added 20 TWh new hydro (120 TWh today)
- D: …added new wind in DE and DK (3x today)
- E: …added 3200 MW new exchange capacity (3 new HVDC cables)

Long-term and seasonal variations in wind and hydro generation

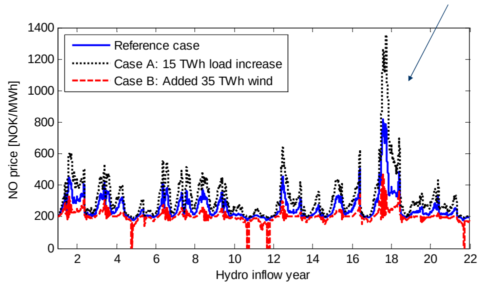


Wind impact on hydro reservoir

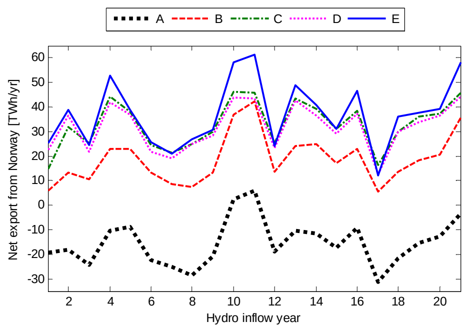


Wind impact on prices in Norway

Wind reduces winter price peaks in dry years



Wind impact on net power exchange

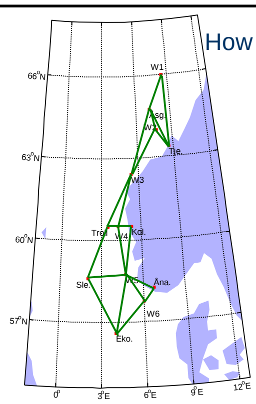


Conclusions

- **Deep sea offshore wind power has very high potential in Norway**
  - **"Unlimited" areas**
  - **Very high wind speeds**
- **Norwegian hydro power is an ideal partner for large-scale wind power**
  - **Wind power effectively relieves constrained energy situations in winter**
  - **Year-to-year variations in wind generation shows very little impact on hydro reservoir utilization and prices**
- **Adding 25 TWh offshore wind, 10 TWh onshore wind and 20 TWh hydro is a plausible scenario**
  - **Exchange capacity should be increased to avoid hydro spillage**

Grid integration

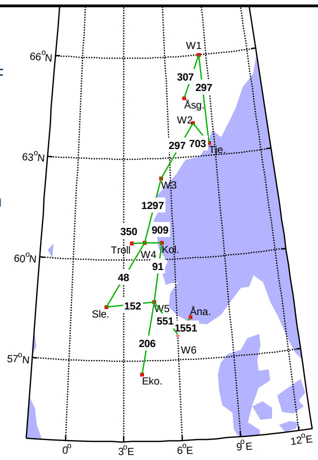
- Problem: connect several (offshore) wind farms to the grid for optimal social benefit
- Input: Location and capacity of wind farms, wind velocity, land connection points and power prices, offshore loads…
- Output (unknowns): Which cables to build and how to dimension them.
- Quickly becomes a difficult problem when there are several wind farms and possible land connection points as well as correlation in wind velocity among sites



How should we design the optimal grid?

-There are so many possibilities!

- New algorithms in development by SINTEF Energy Research can help engineers and decision makers in designing good grid solutions
- Results show dimension of power cables in MW



SINTEF

Takk for oppmerksomheten!

SINTEF

SINTEF Energy Research

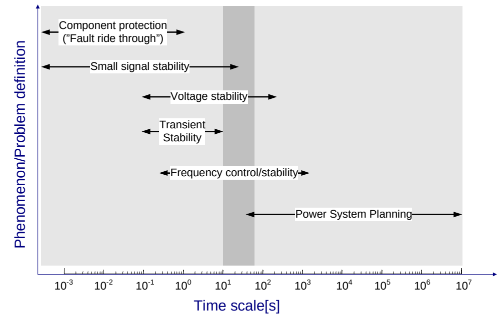
14

Modellering av variabel hastighet vindturbiner for kraftsystemanalyse

Presentasjon Vind FOU, Trondheim - 25. Januar 2008

Jarle Eek

Analyser relatert til vindkraft



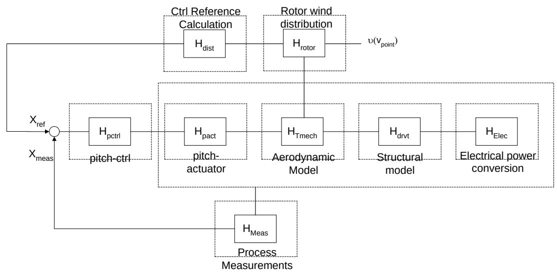
NTNU Norwegian University of Science and Technology - Department of Electrical Power Engineering - Electrical Power Systems Group

Motivasjon for variabel hastighet

- Økt regulerbarhet.
  - Lavere belastning på mekaniske komponenter
  - Bedre utnyttelse av energien i vinden.(optimal regulering) spesielt i lav-vind området.
  - Støy
- Stabiltietsegenskaper.
  - Dekobling fra hastighet gjør generatorene stabile.
  - Delaktig for regulering i kraftsystemet (Regulering av aktiv og reaktiv effekt.)

NTNU Norwegian University of Science and Technology - Department of Electrical Power Engineering - Electrical Power Systems Group

Modell oversikt



NTNU Norwegian University of Science and Technology - Department of Electrical Power Engineering - Electrical Power Systems Group

Modellerte komponenter I

- Vind input.
  - Turbulens: Bånd begrenset hvit støy(Kaimal-spektrum.)
  - Vind felt: lineærfiltrering/"admittansfunksjoner. Effekt av rotorrotasjonen i et inhomogent felt.
  - Moment input til strukturell modell gitt av:

    $P_m=0.5*\rho*A*C_p*v^3$
- Strukturell modell:
  - to masse (: generator + rotor + kobling.)
- Pitch aktuator:
  - 2. ordens servo.

NTNU Norwegian University of Science and Technology - Department of Electrical Power Engineering - Electrical Power Systems Group

Modellerete komponenter II

- Generatorer (PMSG og DFIG):
  - 3. orden(-stator flux dynamikk)
  - 5. orden(Park modell)
  - metning
- Converter:
  - VSC – PWM. Modulasjonsindeks som forsterkning. (Pac=Pdc).
- Regulering:
  - Hastighet/Pitch: PID (full last)
  - Hastighet: PI (del last)
  - Generator: Elektrisk moment/Aktiv effekt, reaktiv effekt. Kaskade- koblede PI regulatorer.
  - Referanseberegninger fra λ_{opt}

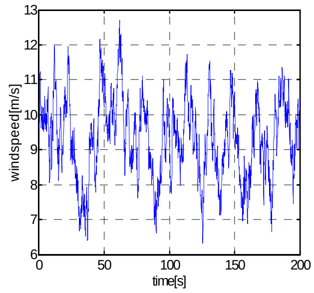
NTNU Norwegian University of Science and Technology - Department of Electrical Power Engineering - Electrical Power Systems Group

Simuleringseksempel

- 944 kVA dobbeltmatet asynkrongenerator
- Genererte tidsserier for vind(u_{av}=10m/s)
- Antagelse vedr. regulering for den aktuelle turbin type.
- Antagelse vedr. turbulensintensitet.
- Antagelse vedr. S_k

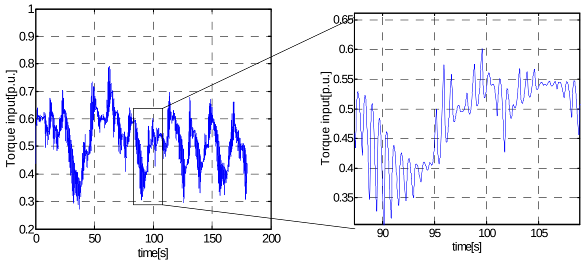
NTNU Norwegian University of Science and Technology - Department of Electrical Power Engineering - Electrical Power Systems Group

Generert vind, Kaimal spekter



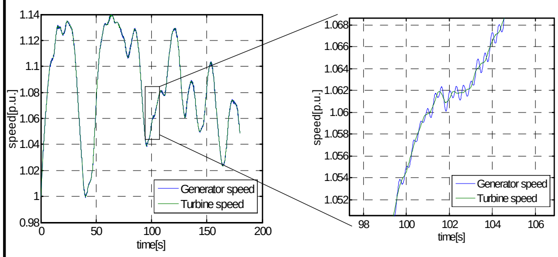
NTNU Norwegian University of Science and Technology - Department of Electrical Power Engineering - Electrical Power Systems Group

Mekanisk moment



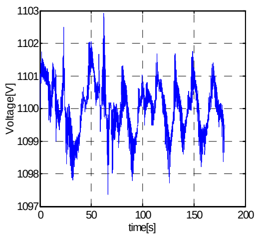
NTNU Norwegian University of Science and Technology - Department of Electrical Power Engineering - Electrical Power Systems Group

Rotor/generatorhastighet



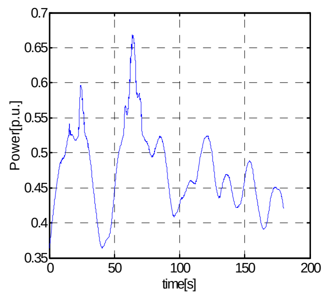
NTNU Norwegian University of Science and Technology - Department of Electrical Power Engineering - Electrical Power Systems Group

DC-link spenning



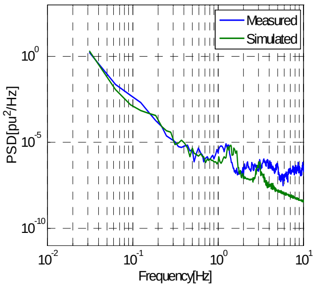
NTNU Norwegian University of Science and Technology - Department of Electrical Power Engineering - Electrical Power Systems Group

Effekt



NTNU Norwegian University of Science and Technology - Department of Electrical Power Engineering - Electrical Power Systems Group

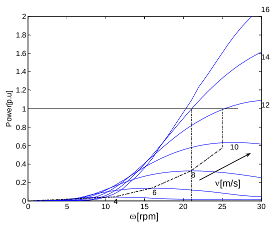
Simuleringseksempel Resultater

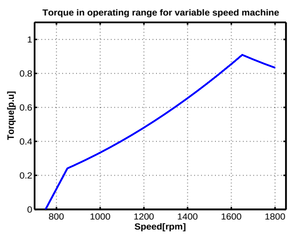


Ekstra slides

NTNU Norwegian University of Science and Technology - Department of Electrical Power Engineering - Electrical Power Systems Group

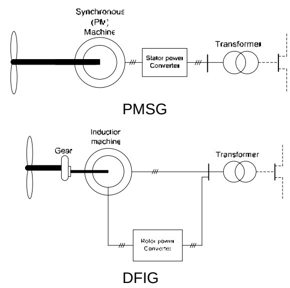
Arbeidsområde for variabel hastighets turbiner





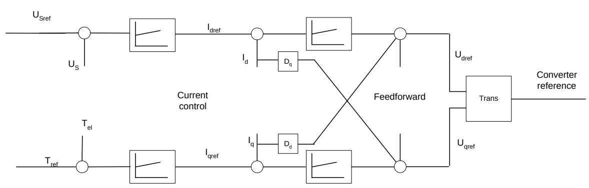
NTNU Norwegian University of Science and Technology - Department of Electrical Power Engineering - Electrical Power Systems Group

Modellerte Generatorer



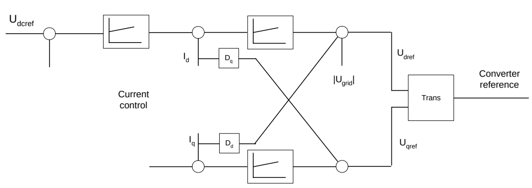
NTNU Norwegian University of Science and Technology - Department of Electrical Power Engineering - Electrical Power Systems Group

Generatorregulering DFIG



NTNU Norwegian University of Science and Technology - Department of Electrical Power Engineering - Electrical Power Systems Group

Regulering av nettvendt converter



NTNU Norwegian University of Science and Technology - Department of Electrical Power Engineering - Electrical Power Systems Group

Systemkrav til vindkraftverk

John Olav Tande
SINTEF Energiforskning AS
John.o.tande@sintef.no

Systemkrav til vindkraftverk

- Prosjekt utført for EBL med støtte fra Statnett
- Utgangspunkt i "Veiledende systemkrav til anlegg tilknyttet regional- og sentralnettet i Norge" (VtA), 2005
- Anbefalinger i VtA vurderes gjennom analyser
- Prosjekt rapporters i teknisk rapport (engelsk); finnes på www.sintef.no/wind
- Rapporten er en faglig anbefaling fra SINTEF, men ikke bindende i forhold til oppdatering av VtA

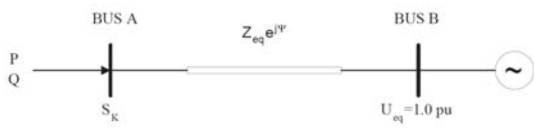
System requirements for wind farms in VtA (2005)

- Operation at varying grid frequency (normal 49.0-50.5 Hz, limited 47.0-51 Hz)
- Operation at varying grid voltage (normal +/- 10 %, reactive capability cosφ = +/- 0.91 ref wind farm point of grid connection)
- Active power control (remote control of maximum production, system for ramp-rate limitation and participation in frequency control)
- Reactive power control (system to operate at two modes: a) set-point cosφ, b) active voltage control with droop)
- Operation in case of grid faults or abnormal grid voltages (fault ride-through for voltages at the grid connection point of the wind farm down to 0.15 pu and with a slow recovery)
- Verification of characteristic properties (analyze impact on system using simulation model and make numerical wind farm model available for Statnett for simulation using PSS/E or similar)

Reactive power and voltage control

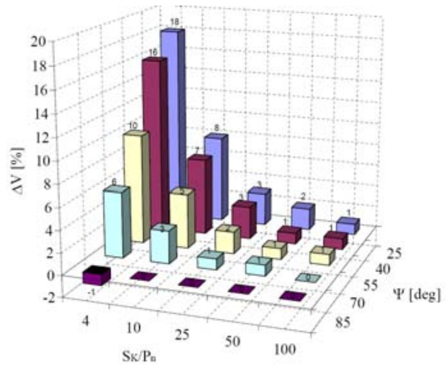
- Reactive power control of wind farms has traditionally been limited to keeping the power factor (cosφ) to unity, or to allowing a small reactive consumption.
- In most new grid codes however, there are requirements for wind farms to be able to produce or consume certain amounts of reactive power, and also to be able to automatically control the reactive power for contributing to a stable grid voltage.
- This seems rational as wind farms can then add to voltage control in the same manner as other utility scale power plants and allow for connecting more wind power to the grid.
- The question is rather if the reactive power capacity of a wind farm shall be cosφ = 0.91 (capacitive and inductive) as suggested in the VtA, or something else.
- The basic reasoning is that reactive capacity comes at a cost, and a rational requirement should strike a balance between that and the value of having such capacity.

Reactive power and voltage control

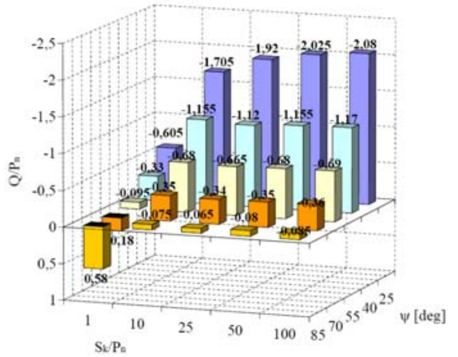


- The analysis is kept on a general basis representing the grid by a Thevenin equivalent and the wind farm as a source of active and reactive power.
- This approach is taken to make the results representative for any type of wind turbine technology as characterised by its P and Q feed-in and any grid as characterised by its Thevenin equivalent.

Voltage increment due to injection of wind power Pn with a power factor equal to 1.0.



Reactive power feed-in (Q/Pn) for maintaining zero voltage increment



Reactive power and voltage control

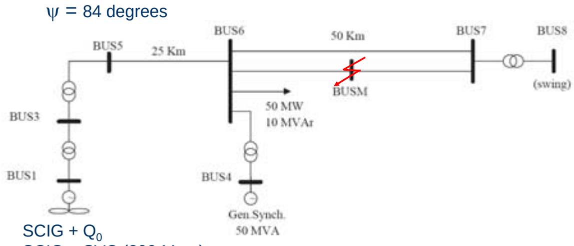
- Summing up it seems reasonable to require that wind farms shall be able to contribute with a power factor between unity and 0.95.
- The reasoning behind this is that reactive power is mainly needed from large wind farms to help maintain an acceptable voltage level.
- In strong grids the voltage is expected not be changed very significant by the wind farm, and hence this will not be setting any particular requirement to the reactive contribution from wind farms.
- In weak grids the voltage may deviate significantly due to in-feed power, and hence this may set requirements to the reactive contribution from the wind farm (or other generator).
- The analysis shows that in such weak grids, and excluding the extreme case of Sk/Pn = 1, an amount of reactive power corresponding to a power factor between unity and 0.95 (capacitive and inductive) is sufficient for maintaining a stable voltage.
- Indeed, the analysis presented here is not a substitute for any detailed grid study that should be prepared as part of planning a large wind farm, and such detailed assessment may come up with suggesting different reactive power requirements.
- This may be due to special grid conditions not taken into account in this report. Such requirements should however then be the exception and not the general rule.

Wind farm response to voltage dips

- Until a few years back the rule was that wind farms should disconnect in case of grid disturbances, e.g. voltage dips.
- The idea was to protect the wind turbines as low voltage could cause over-speed and mechanical failures, but also that tripping of some small generation would anyhow not have any significant impact on system stability.
- The development of large wind farms changed this as tripping of such can possibly lead to cascading faults and system instability.
- It is worthwhile to notice that implicit in this new way of thinking is also a recognition of wind farms as a source of firm power, i.e. the system is operated relying on the wind power generation.
- Low-voltage fault ride-through capabilities of wind farms can be achieved in a variety of ways.
- The challenge is basically that as the voltage drops the current output must increase or else the turbines will accelerate to over-speed.
- Blade pitching can be activated to limit the aerodynamic power, and by this reduce current and acceleration, but not immediately.
- Hence, the lower the voltage the wind farm shall be able to ride-through, the bigger the challenge.
- Striking at a balanced requirement is the aim.

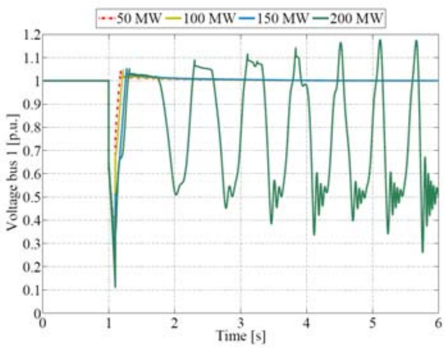
Test grid

S_k = 605 MVA
ψ = 84 degrees

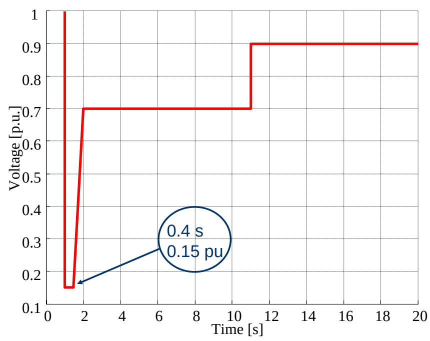


SCIG + Q_0
SCIG + SVC (200 Mvar)
DFIG

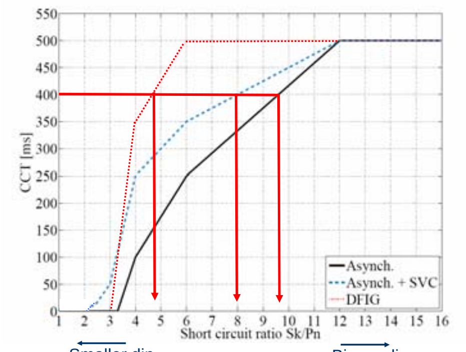
Wind farm (SCIG + SVC (200 Mvar)) response to voltage dip



Fault ride-through requirement in VtA



Critical clearing time (CCT) of fault



Smaller dip   Bigger dip

Low-voltage fault ride-through requirement

- The requirement on fault ride-through is assessed considering the ability of various wind farm technologies to meet the requirement, and the likelihood of the given voltage dip and slow recovery to appear as a consequence of a short-circuit fault in the up-stream regional or transmission network.
- Summing up on the assessment it seems reasonable to require fault ride-through of a dip with a duration of 0.4 s, i.e. in accordance with the response time for protection equipment to trip a faulted line.
- The dip going down to 0.15 pu may pose a challenge for connecting wind farms to (very) weak grids, e.g. Sk/Pn < 10 depending on the wind farm technology, though must be judged also on the likelihood of such deep dips occurring.
- Possibly, a reasonable requirement could be a dip down to 0.25 pu.
- The requirement of 0.7 pu voltage for 9 s seems not well justified. Instead it is suggested that the voltage after the dip can return to 0.9 pu within a half second or thereabout.

Oppsummering og konklusjon

- Rasjonelt at det stilles systemkrav til vindkraftverk
- Et krav til reaktiv ytelse tilsvarende cosφ = 0.95 virker rimelig, fortrinnsvis med tanke på at store vindparker skal kunne bidra til å holde spenningen på akseptabelt nivå
- Et krav til drift gjennom spenningsdipp synes rasjonelt, fortrinnsvis som en kortvarig dipp (0.4 s) ned til 0.25 pu (evnt. 0.15 pu), og hurtig tilbake til normal spenning (minimum 0.9 pu)
- Krav må balansere kostnad og behov – overstående søker dette.

SINTEF Energiforskning AS
Adresse: 7465 Trondheim
Telefon: 73 59 72 00

SINTEF Energy Research
Address: NO 7465 Trondheim
Phone: + 47 73 59 72 00