International Energy Agency R&D Wind

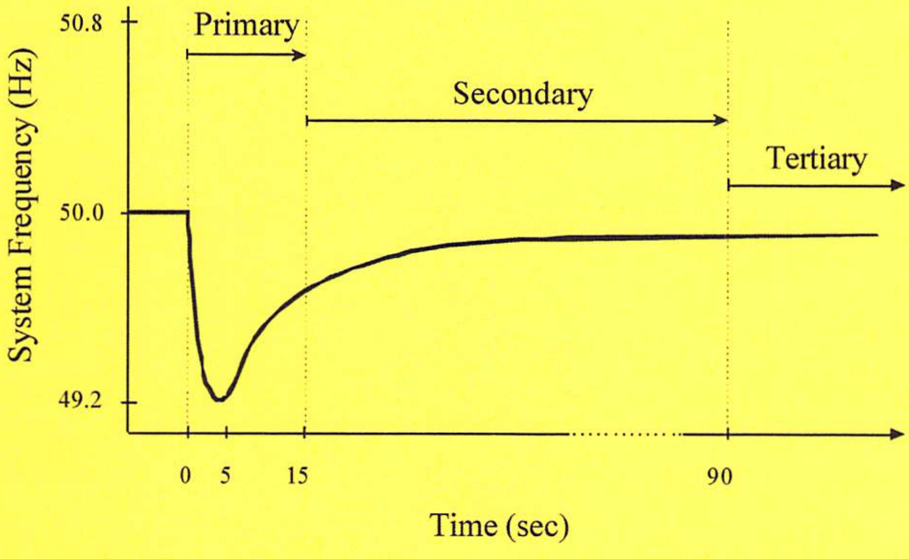
INTERNATIONAL ENERGY AGENCY

Implementing Agreement for Co-operation in the Research and Development of Wind Turbine Systems
ANNEX XI

44th IEA Topical Expert Meeting

System Integration of Wind Turbines

Dublin, Ireland, November 2004
Organised by: SEI



Role of Primary and Secondary reserve in managing frequency excursions

FOI SWEDISH DEFENCE RESEARCH AGENCY

Scientific Co-ordination:
Sven-Erik Thor
FOI, Aeronautics - FFA, 172 90 Stockholm, Sweden

FOI
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RESEARCH AGENCY

IEA R&D WIND ANNEX XI
The Operating Agent

January 12, 2005

TO:

- Participants in IEA R&D Wind Annex XI
- Participants in the meeting
- Other interested parties

RE: Proceedings from Topical Expert Meeting

Dear Colleague,

Please find attached documentation from Topical Expert Meeting #44 "System Integration of Wind Turbines"

At the end of the document there is a summary of the meeting. This summary is also published on the internet, www.windenergy.foi.se/IEA_Annex_XI/ieaannex.html. If you need more copies, please contact Gunnel Backström on E-mail, gunnel.backstrom@foi.se.

Sincerely

S-E Thor

Sven-Erik Thor

Attachment: Proceedings TEM #44

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International Energy Agency R&D Wind

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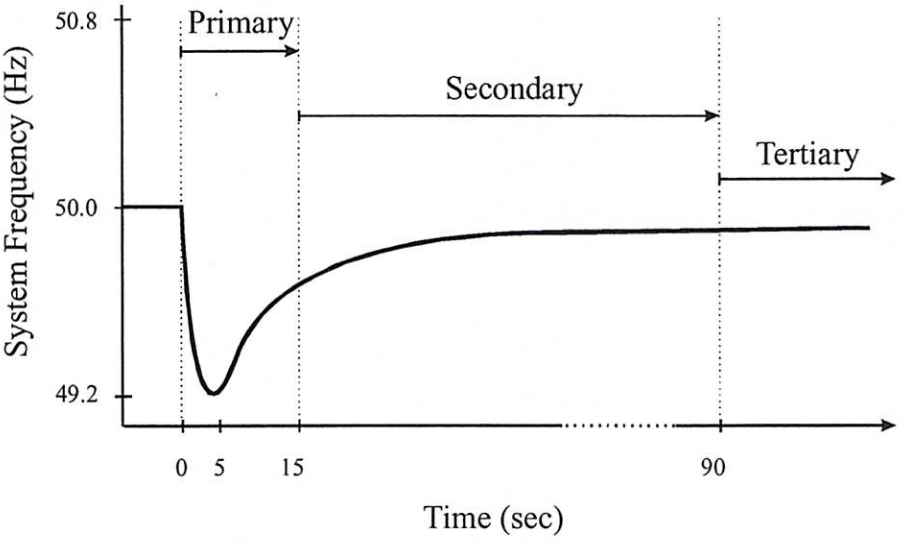

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IEA R&D Wind

Topical Expert Meeting #44
Systems Integration of Wind Turbines

ANNEX XI
BASE TECHNOLOGY INFORMATION EXCHANGE

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The objective of this Task is to promote wind turbine technology through cooperative activities and information exchange on R&D topics of common interest. These cooperative activities have been part of the Agreement since 1978.

The task includes two subtasks. The objective of the first subtask is to develop recommended practices for wind turbine testing and evaluation by assembling an Experts Group for each topic needing recommended practices. For example, the Experts Group on wind speed measurements published the document titled "Wind Speed Measurement and Use of Cup Anemometry".

The objective of the second subtask is to conduct joint actions in research areas identified by the IEA R&D Wind Executive Committee. The Executive Committee designates Joint Actions in research areas of current interest, which requires an exchange of information. So far, Joint Actions have been initiated in *Aerodynamics of Wind Turbines, Wind Turbine Fatigue, Wind Characteristics, Offshore Wind Systems and Wind Forecasting Techniques.* Symposia and conferences have been held on designated topics in each of these areas.

In addition to Joint Action symposia, Topical Expert Meetings are arranged once or twice a year on topics decided by the IEA R&D Wind Executive Committee. One such Expert Meeting gave background information for preparing the following strategy paper "Long-Term Research and Development Needs for Wind Energy for the Time Frame 2000 to 2020". This document can be downloaded from source 1 below.

Since these activities were initiated in 1978, more than 60 volumes of proceedings have been published. In the series of Recommended Practices 11 documents were published and five of these have revised editions.

All documents produced under Task XI and published by the Operating Agent are available to citizens of member countries from the Operating Agent, and from representatives of countries participating in Task XI.

More information can be obtained from:

1. www.ieawind.org
2. www.windenergy.foi.se/IEA_Annex_XI/ieaannex.html

IEA R&D Wind - List of Topical Expert Meetings

For more informatiuon visit http://www.windenergy.foi.se/ and click on IEA
Documents can be obtained from Sven-Erik Thor at trs@foi.se

Nr	Title	Date	Year	Location	Country
43	Critical Issues Regarding offshore Technology and Deployment	March	2004	Stockholm	Sweden
42	Acceptability in Implementation of Wind Turbines in Social Landscapes	March	2004	Kolding	Denmark
41	Integration of Wind and Hydropower Systems	November	2003	Portland	USA
40	Environmental issues of offshore wind farms	September	2002	Husum	Germany
39	Power Performance of Small Wind Turbines not connected to the Grid	April	2002	Soria, CIEMAT	Spain
38	Material Recycling and Life Cycle Analysis (LCA)	March	2002	Risø	Denamrk
37	Structural Reliability of Wind Turbines	November	2001	Risø	Denmnark
36	Large Scale Integration	November	2001	Newcastle	UK
35	Long term R&D needs for wind energy. For the time frame 2000 – 2020	March	2001	Petten	the Netherlands
34	Noise Immission	November	2000	Stockholm	Sweden
33	Wind Forecasting Techniques	April	2000	Boulder	Usa
32	Wind energy under cold climtes	March	1999	Helsinki	Finland
31	State of the art on Wind Resource Estimation	October	1998	Lyngby	Denmark
30	Power Performance Assessments	December	1997	Athens	Greece
29	Aero-acoustic Noise of Wind Turbines	March	1997	Milano	Italy
28	State of the art of aeroelastic codes for wind turbines	April	1996	Lyngby	Denmark
27	Current R&D needs in wind energy technology	September	1995	Utrecht.	Netherlands
26	Lightning protection of wind turbine generator systems and EMC problems in the associated control systems	March	1994	Milan	Italy
25	Increased loads in wind power stations (wind farms)	May	1993	Gotherburg	Sweden
24	Wind conditions for wind turbine design	April	1993	Risø	Denmark
23	Fatigue of wind turbines, full-scale blade testing and non-destructive testing	October	1992	Golden, Colorado	USA
22	Effects of environment on wind turbine safety and performance	June	1992	Wilhelmshaven	Germany
21	Electrical systems for wind turbines with constant or variable speed	October	1991	Gothenburg	Sweden
20	Wind characteristics of relevance for wind turbine design	March	1991	Stockholm	Sweden
19	Wind turbine control systems-strategy and problems	May	1990	London	England
18	Noise generating mechanisms for wind turbines	November	1989	Petten	Netherlands
17	Integrating wind turbines into utility power systems	April	1989	Herndon	USA
16	Requirements for safety systems for LS WECS	October	1988	Rome	Italy
15	General planning and environmental issues of LS WECS installations	December	1987	Hamburg	Germany
14	Modelleing of atmospheric turbulence for use in WECS rotor loading calculations	December	1985	Stockholm	Sweden
13	Economic aspects of wind turbines	May	1985	Petten	Netherlands
12	Aerodynamic calculation methods for WECS	October	1984	Copenhagen	Denmark
11	General environmental aspects	May	1984	Munich	Germany
10	Utility and operational experience from major wind installations	October	1983	Palo Alto	California
9	Structural design criteria for LS WECS	March	1983	Greenford	UK
8	Safety assurance and quality control of LS WECS during assembly, erection and acceptance testing	May	1982	Stockholm	Sweden
7	Costing of wind turbines	November	1981	Copenhagen	Denmark
6	Realibility and maintenance problems of LS WECS	April	1981	Aalborg	Denmark
5	Environmental and safety aspects of the present LS WECS	September	1980	Munich	Germany
4	Rotor blade technology with special respct to fatigue design	April	1980	Stockholm	Sweden
3	Data acquisition and analysis för LS WECS	September	1979	Blowing Rock	USA
2	Control of LS WECS and adaption of wind electricity to the network	April	1979	Copenhagen	Denmark
1	Seminar on structural dynamics	October	1978	Munich	Germay

INTRODUCTORY NOTE
IEA Topical Expert Meeting #44
on
Electricity Power System and Market Operation with High Wind Power Penetration

John McCann, Morgan Bazilian, Mark O'Malley

1. CONTEXT FOR MEETING

Wind power penetration is increasing rapidly in many countries worldwide. In the countries currently leading the field in wind energy deployment, wind power capacity penetrations of up to 30% have been attained[1]. The interaction of wind energy and the power system has emerged as a potentially significant obstacle to increased penetration. There are issues ranging from operating reserves and frequency control, to the ability of the current grid system to accommodate additional generation. Individual countries with high wind power penetration may currently rely upon interconnection with neighboring countries for provision of ancillary services that support the high local penetration. As power systems and markets are not necessarily delineated by political boundaries, the technical assessment of the effects of high wind penetration upon these may better be carried out on a system-wide, rather than individual country, basis. In some cases the cost (both direct and external) of providing required ancillary services (including various classes of reserve) exhibits an exponentially increasing relationship with wind penetration. Thus, the availability of system ancillary services may be a limiting factor on the rate of deployment of wind power.

In addition to creating environmental benefits, it has been suggested that the nature of wind generation may impact on the operation of electricity systems in such a way as to increase the requirement for reserve. This is because wind generation has a number of physical and technical characteristics that are very different to the conventional generation it displaces. Historically these characteristics may include:

- a lack of inertial response;
- a limited ability to provide reserve;
- intermittent, and potentially unpredictable, electrical output that is highly correlated with that from other windfarms;
- distribution connection and self-dispatch (for smaller windfarms); and
- a varied ability to ride-through system faults.

The impact that wind generation will have on the electricity system as a whole will depend on a number of factors, which include:

- total capacity of wind installed and its proportionate size to the total system;
- size and geographic diversity of individual wind developments;
- type of wind generators installed - potentially determined by compliance with the requirements of the Grid Code and connection agreements;
- ability to accurately forecast wind generation;
- overall size of the electricity system;
- size, type and mix of conventional (and pumped storage) generating plant;
- the level, and contractual nature, of interconnection with other electricity systems.

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[1] Installed wind capacity as a percentage of installed capacity. It is recognised that there other, perhaps more relevant, metrics to use.

Addressing these issues requires technical knowledge of wind generators and their associated power electronic interfaces, as well as power system operation. Grid codes also need to accommodate the unique operational aspects of wind power explicitly and fairly. It is essential to provide robust solutions to all of these concerns in order to mitigate decreased system security and reliability.

The primary service upon which a high wind penetration will place increased demands will be the provision of reserves. System operators must constantly balance the demand for, and generation of electricity over time horizons from fractions of a second, through minutes, hours, days to weeks and even months ahead. System operators will plan to operate the system based on a forecast of demand and a schedule of planned power station operation. Severe frequency excursions are normally avoided through the use of reserve to limit the extent of a frequency divergence. Frequency excursions can take many forms, from slow-acting inaccuracies in the forecasting of demand, where demand and generation drift out of balance over time, to sudden shocks to the system following the loss of significant generation or demand due to a plant or network fault. Consequently, the provision of reserve has a number of aspects, related to the timeframe over which it is required to operate and the type of incident to which it responds. Hence, reserve requirements range from small short-term frequency variations to load-following over longer time frames, and further include the need to respond to sudden large energy imbalances following the loss of a major generating unit. Figure 1 illustrates the type of reserve that may be utilised following a frequency incident[2].

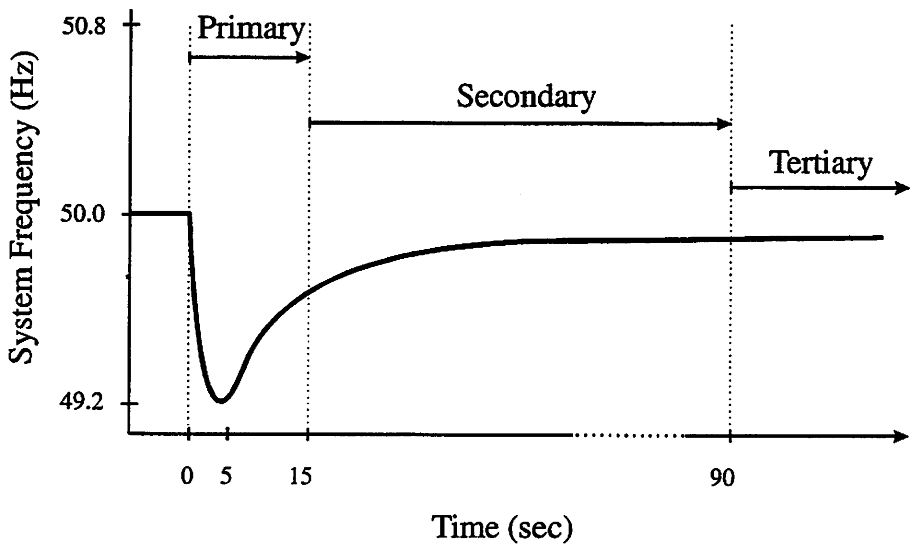


Figure 1 - Role of Primary and Secondary reserve in managing frequency excursions

The other system services which increased wind power may place higher demands upon include voltage regulation, reactive power provision, network capacity and network management. The requirements for a majority of these services can generally be met through network reinforcement and additional network resources and while the costs for these may rise as penetration increases, and local limits may be imposed upon wind penetration, the costs are not likely to rise at a rate where they become the primary limiting factor on wind power penetration.

If it is taken as a given that the availability of reserves and back-up capacity will present the ultimate limit on wind penetration, then electricity system and market design and operation to optimize the provision and dispatch of reserves and to obtain adequate back-up capacity should be a focus for attention within jurisdictions where a high wind penetration is planned. In some jurisdictions current system planning criteria or market design incorporate conservative assumptions on the extra demand which wind generation will place upon reserves and the capability of wind generators to provide reserve. In some markets the incentives for investment in new generation capacity may not be

[2] This figure has been made for the Irish system.

sufficient to bring about the changes to conventional generation mix which may be required to integrate a high wind penetration into a system. It is also apparent that there are no agreed standard methods for analysing the impact of increasing wind penetration upon electricity system operation and reserves provision.

2. Benefits of IEA Cooperation

While it is evident from the literature that substantial research has been undertaken in the field of wind power integration within power systems, it is also apparent that there is a diversity in approach to the analysis of the impacts of wind power upon electricity systems. This diversity may be a product of the diversity of electricity system characteristics and market designs. Attaining agreement among wind interests and system operators upon a standardized approach or set of approaches may facilitate a steady growth of wind power penetration within electricity systems internationally. It would be of particular benefit if a common position could be reached by wind interests and electricity system operators on the following:

(i) The methods for assessing power system adequacy and security in systems with a high wind power input.

(ii) Whether the standard methods for power system analysis, planning and operation will adequately serve in future power systems with high wind penetration.

In view of the varied success to date in achieving unanimity on an approach to integrating wind power within electricity systems, it will be critical to the development of the wind industry that fora are established where specialists in both wind power and power systems operation can debate the issues and reach agreement. **One such forum is the IEA Wind R&D Agreement and it is proposed that a Topical Expert Meeting under Annex 11 of this agreement be held to inform participants of the latest developments internationally and to establish whether there is common ground for further work.**

3. Some relevant references

A number of national studies have recently been initiated in various jurisdictions. Reports which have been published include:

USA

"Wind Power Impacts on Electric Power System Operating Costs: Summary and Perspective on Work to Date" NREL 2004

"Assessing the Impacts of Wind Generation on System Operations at Xcel Energy-North and Bonneville Power Administration", Electrotek Concepts Inc., Bonneville Power Administration and Xcel Energy Inc.

"The Effects of Integrating Wind Power on Transmission System Planning Reliability and Operations", New York State Energy Research and Development Authority

"Assessing Wind Integration Costs with Dispatch Models: A Case Study of PacifiCorp" NREL

Australia

"Intermittent Generation in the National Electricity Market", Market Development

Europe

"Integrating wind power in the European Power Systems – Prerequisites for Successful and Organic Growth" UCTE Position Paper, May 2004

Ireland

"Operating Reserve Requirements as Wind Power Penetration Increases in the Irish Electricity System" Sustainable Energy Ireland 2004

A list of some relevant references that might be useful to the deliberation of the group is also included:

Directive 2001/77/EC of the European Parliament and of the Council of 27th September 2001 on the *Promotion of Electricity Produced from Renewable Energy Sources in the Internal Electricity Market.* Directive 2001/77/EC. 2001. http://europa.eu.int/scadplus/leg/en/lvb/l27035.htm

European Commission, *Energy for the Future: Renewable Sources of Energy*, White Paper for a Community Strategy and Action Plan. 1997.http://europa.eu.int/scadplus/leg/en/lvb/l27023.htm

Arnott, I. *Intermittent Generation in the National Electricity Market*, Proceedings of Australian Wind Energy Agency. 2002, Adelaide

Garrad Hassan, *Impact of Increased Levels of Wind Penetration on the Electricity Systems of the Republic of Ireland and Northern Ireland: Final Report, 2003*, Commission for Energy Regulation/OFREG NI.

Hirst, E., *Interactions of Wind Farms with Bulk Power Operations and Markets.* www.ehirst.com, 2001

Doherty, R. and M. O'Malley. *Quantifying Reserve Demands Due to Increasing Wind Power Penetration,* Proceedings of Proceedings of 2003 Power Tech Conference. 2003, Bologne, Italy

Hirst, E., *Integrating Wind Energy in the Bonneville Power Administration (BPA) Power System. www.ehirst.com*, 2002

Outhred, H. *Some Operation and Investment Issues for Wind Farms in a Restructured Electricity Industry*, Proceedings of ANSZES Proceedings. 2002, Adelaide

Econnect, *The Impacts of Increased Levels of Wind Penetration on the Electricity Systems of the Republic of Ireland and Northern Ireland, 2003*, Response to CER from Airtricity.

Persaud, S., *Wind Power Variability and Power System Operation, 2003*, Queen's University: Belfast.

Department of Enterprise Trade and Investment and The Department of Public Enterprise, *Final Report on North/South Energy Studies.* August 2001. www.energy.detini.gov.uk

Commission for Energy Regulation (CER), *CER Letter to ESBNG regarding ESBNG request to extend the limitation of New Wind Connections*http://www.cer.ie/docs.asp?Type=Year&Year=2003&Image=images/CERDocs/cer03310.pdf. CER/03/310, 2003 http://www.cer.ie/cerdocs/cer03310.pdf

Slootweg, J., G., *Modelling Wind Turbines for Power System Dynamics Simulations: an Overview.* Wind Engineering, 2003, vol 28 issue 1, ppXXX-YYY

McArdle, J., *Dynamic Modelling of Wind Turbine Generators and the Impact on Small Lightly Interconnected Grids.* Wind Engineering, 2003, vol 28 issue 1 ppBBBB

Causebrook, A. and B. Fox, *Decoding Grid Codes to Accommodate Diverse Generation Technologies.* Wind Engineering, 2003, vol 28 isssue ppNNNN

Johnson, A. and H. Urdal, *Technical Connection Requirements for Wind Farms.* Wind Engineering, 2003 vol 28 issue 1, pp

Smith, P. *Impact of Increasing Wind Generation on the Transmission System in the Republic of Ireland*, Proceedings of Symposium Neptune CIGRE. 1997

Commission for Energy Regulation Ireland, *Funding of Grid Upgrade Development Programme for Renewables,* Consultation Paper. *CER/03/016*, 2003.http://www.cer.ie/cerdocs/cer03016.pdf

Agenda for Annex 21 meeting

1. Progress of works (summary by JOT + by individual participants; 5-10 minutes each)
2. Agree on benchmark test procedure of wind turbine/wind farm models (draft to be issued)
3. Measurement data and model descriptions in database (e-room), incl prospects for new data/measurements to be added
4. IEA Annex 21 "white paper" (Dynamic models of wind farms for power system studies - status by IEA Wind R&D Annex 21), EWEC'04 (draft to be issued)
5. Report with model descriptions (draft to be issued)
6. Public web page (http://www.energy.sintef.no/wind/IEA.asp)
7. Planning of further works / consider written progress/status reports by each participant
8. Issues for next meeting in Portugal (spring 2005)/further meetings (Netherlands fall 2005)
9. Any other issues/information/EU call for proposals

SINTEF SINTEF Energy Research

Status Report

IEA R&D Wind: Annex XXI: Dynamic models of wind farms for power system studies

Kjetil Uhlen, John Olav Tande
(SINTEF Energy Research)

SINTEF SINTEF Energy Research

Topics:

- Meetings and participation
- progress of works (brief technical)
  - Models
  - Measurement database
  - Model validation (Benchmark test procedure)
- planned activities for the next period

http://www.energy.sintef.no/wind/IEA

Administration and organization of meetings

- ExCo meetings
  - ExCo meeting 53 in Chester, UK 18-19 May 2004
  - ExCo meeting 54 in Oulu, Finland, 5-6 October 2004
- Annex meetings
  - Annex meeting #4 was organized at Chalmers, Sweden 3 March 2004
  - Annex meeting #5 was organized in Dublin, Ireland 8 November 2004
  - Further meetings (tentatively) spring 2005 in PT and fall 2005 in NL
- Commitments to join the Annex
  - Annex members are from SE, FI, NO, PT, NL, DK, USA, UK and IE

Progress VS Objectives

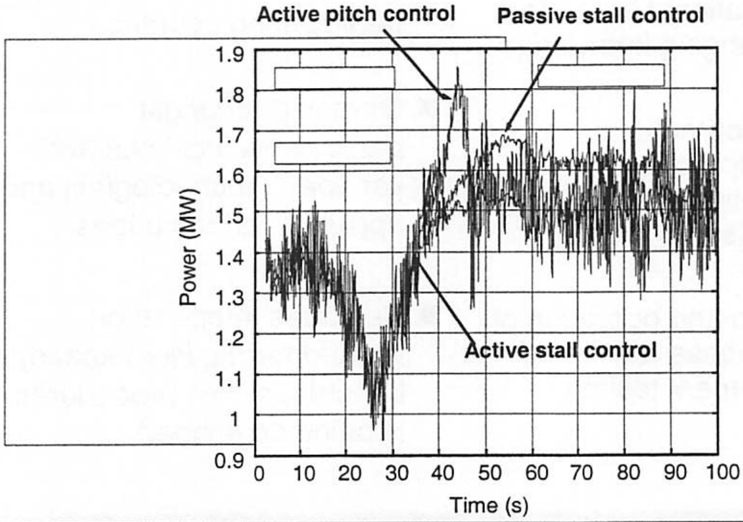
Immediate Objectives	Status pr date
■ Establishment of an international forum for exchanging knowledge	■ Annex XXI is active with 9 participating countries
■ Development, description and validation of wind farm models	■ On-going amongst participants incl fixed and var speed technologies, and applying various codes
■ Set-up and operation of a database for benchmark testing	■ Database in operation (4 wind farms, fixed speed); benchmark test procedures is being developed

Progress of works

- **Dynamic wind farm models – overview**

Participant	Tool	Comment
Chalmers	Matlab, PSSE, DigSilent	Model library in Matlab Fixed speed model verified Variable speed model verification ongoing
ECN/TUD	Matlab	Fixed and variable speed models Models and study reported (ERAO II)
INETI	InPark, Matlab	Fixed speed models
NREL	Vissim, PSSE	Fixed and variable speed models; development and verification of PSSE models in cooperation with various entities
Risø	Matlab, DigSilent	Fixed and variable speed models Matlab model library available at www.iet.aau.dk/Research/wts.htm www.iet.aau.dk/Research/spp.htm
SINTEF	Matlab, PSSE, SIMPOW, PSCAD	Fixed and variable speed models Fixed speed model verified Variable speed model verification ongoing
UCD	Matlab	Fixed and variable speed models
UMIST	Matlab, PSCAD	Fixed and variable speed models DFIG models available at http://www.dgsee.umist.ac.uk/dfig/index.html
VTT	ADAMS, Matlab, PSCAD	Models are developed combining ADAMS, PSCAD and Matlab

Dynamic simulation of wind turbines
(fixed speed – normal operation - effect of pitch control system)



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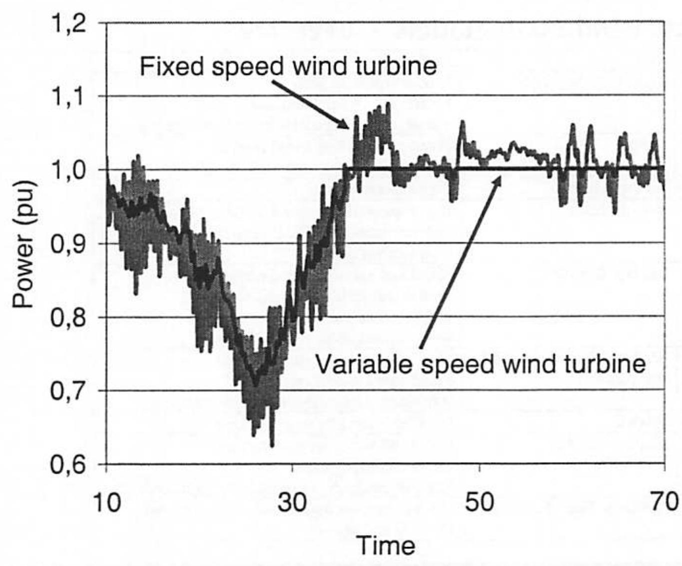
Dynamic simulation of wind turbines
(normal operation)



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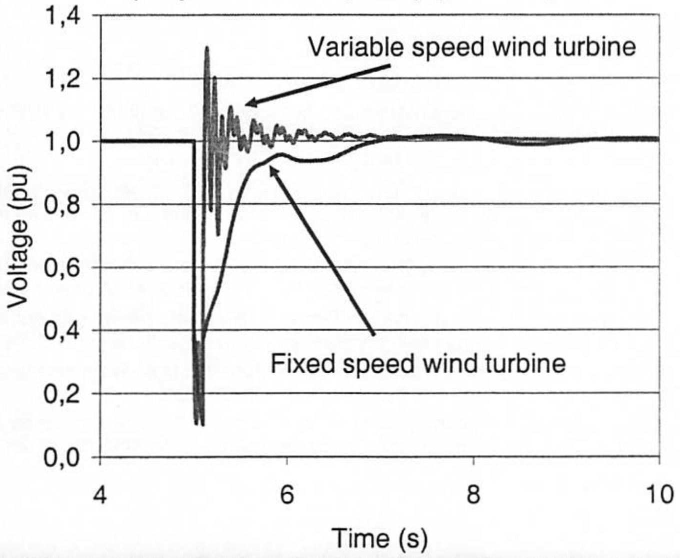
Dynamic simulation of wind turbines

(response to temporary grid fault)



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Progress of works

- **Dynamic wind farm models - summary**
  - In general the progress is good on model development.
  - Models are available on various platforms (Matlab, PSSE etc), and the Annex participants take model verification seriously providing confidence
  - The common major challenge is seemingly to verify the response of models on grid faults such as severe voltage dips
  - Relevant measurements are not easy to obtain and a further difficulty is that the response is very dependent on the detailed wind turbine control
  - A spin-off from the Annex works is to update IEC 61400-21 to specify procedures for measurements/documentation of the response of wind turbines on voltage dips, i.e. lay the foundation for model verifications
  - The proposal is now approved by IEC TC 88 and work has started aiming to prepare a draft revision of IEC 61400-21 by March 2005.

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Progress of works - database

- **Set-up and operate database**
  - Measurement database is established as an "Eroom"
  - Work is ongoing to collect more measurements and the database will be expanded significantly according to the Annex goals by end of 2004.
  - Examples of new data to be added before end 2004 are:
    - A new example dataset from Risø considering fixed speed wind turbines are already received and is now ready to be uploaded; i.e. to be used in addition to data from Alsvik for benchmark testing.
    - Data from Smøla, NO, 20x2 MW fixed speed wind turbines (Bonus), measurements are ongoing by SINTEF and data is now ready to be uploaded
    - Data from 70 MW wind farm in Donegal, IE, fixed speed, "grid code compliant" wind turbines (Bonus with thyristor switched capacitors) by U College Dublin
  - Work is still in progress on collecting measurements from variable speed wind turbines, and during transient events, e.g. voltage dips.
  - As soon as consensus on benchmark testing is reached, the database will be updated to include complete data and descriptions to facilitate such tests.

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Progress of works – Model validation

- **Set-up procedures for benchmark testing**
  - The development of procedures for benchmark testing of models is progressing according to plan expecting consensus by fall 2004.
  - The benchmark test may include both validation against measurements and model-to-model comparisons.
  - Test on dynamic operation during normal fault free conditions:
  - Test on response to sudden temporary voltage drop:
  - Measurement data from Alsvik wind farm are now used as a first case for testing the proposed benchmark procedure.

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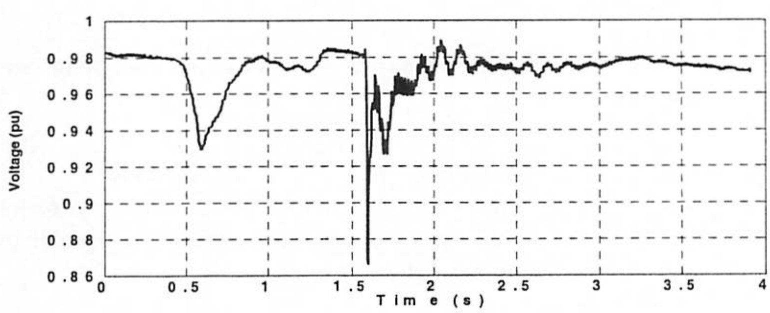
Benchmark test procedure

- Dynamic operation during normal conditions:
  - Input: Windspeed time series (and Voltage, V(t))
  - Output:
    - time series plot of active power output, P(t), Q(t), (V(t))
    - power spectral density of active power output
    - short-term flicker emission
    - Plots of Q versus V and Q versus P
- Response to voltage dip:
  - Input: Voltage time series (and windspeed or constant torque)
  - Output:
    - time series plot of active and reactive power output
    - (time series of voltage at wind turbine terminals)

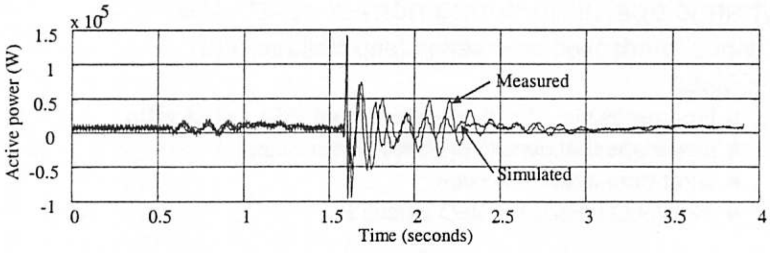
Benchmark test (example)



Response to (minor) voltage dips:

Measurements from Alsvik wind farm (4x180 kW, fixed speed, stall controlled)

Benchmark test (example)



Measurements and simulations prepared by Chalmers on Alsvik wind farm (4x180 kW, fixed speed, stall controlled) response of (minor) voltage dip

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Progress of works

- **Reports etc**
  The following reports have been prepared by the OA since last progress report:
  - **Abstract for EWEC'04, London, UK 22-25 November 2004 "Dynamic models of wind farms for power system studies – status by IEA Wind R&D Annex 21" accepted for oral presentation – paper in progress due by 22 November 2004.**
  - **The public homepage for the Annex continues to being updated: http://www.energy.sintef.no/wind/IEA**

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Planned work for next period

- Prepare IEA Annex 21 "white paper" (Dynamic models of wind farms for power system studies – status by IEA Wind R&D Annex 21) for oral presentation at EWEC'04 in London, UK 22-25 November 2004.
- Continue work to agree on benchmark test procedures
- Collect and add measurement data / descriptions to the database
- Annex meeting #6 to be held at INETI (Portugal) spring 2005.
- Prepare report with model descriptions

Further work towards next meeting

- Finalising and presentation of model description report
  - (circulate drafts as soon as possible, SINTEF starts before February, all feedback by end of March)
- Presentation/discussion of "benchmark" simulation results
  - Results to be sent by end of April
  - Next step: Paper, report?
- Recommendations:
  - ..on the choice and use of models for various power system studies
  - Rough draft on how to approach this will be prepared
  - Discuss how to report this (IEA recommendation?, technical paper?, report?)

Conclusion

- Progress is according to time schedule
- Accelerated efforts is expected to be taken by the Annex to:
  - extend the database to include measurements from var speed turbines
  - develop benchmark test procedures according to target date
  - improve confidence in models and their widespread use ("white paper")
  - Provide recommendations on the choice and use of wind farm models
- The current situation with on the one hand very varying level of confidence and knowledge about wind farm grid interaction modelling, and on the other hand ever larger wind farm projects being planned, the importance and relevance of the Annex works is highlighted

sei SUSTAINABLE ENERGY IRELAND

System Integration Issues

John Mc Cann, Sustainable Energy Services, SEI, Dublin

IEA Wind R&D TEM44, Dublin, 9th Nov 2004

NDP

Accommodating High Wind Power Penetration in Electricity Power Systems

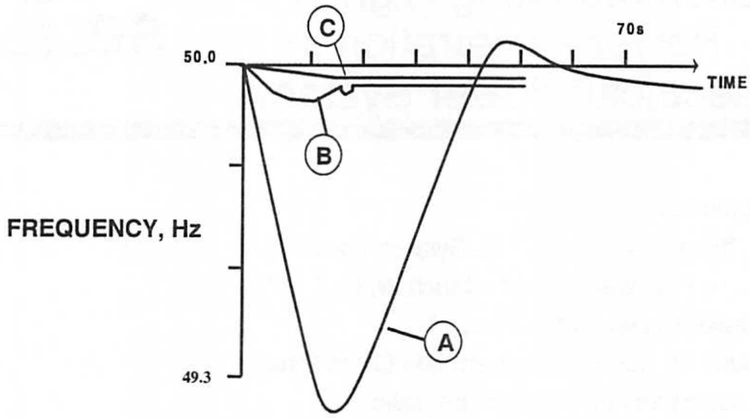
sei SUSTAINABLE ENERGY IRELAND

- Fundamental Question
  - "How Much Wind Can System Take"
    - Followed by "How Much Will it Cost"
- Answer "It Depends Upon…."
- Countries with High Penetration Often Cited
  - Comparisons May not be Valid
  - Not Representative of Complete Power System
  - Can Rely on Neighbours for Support
- Question will Become More Critical with Increasing Penetration Across Whole Power Systems

Irish Experience

- Irish System Characteristics:
  - Small Size: 5550MW ROI, 1837 NI
  - Tight Capacity Margins, 4568MW Winter Peak ROI
  - Isolated Island System

Frequency Regulation



Power System frequency response to loss of generation

A: Irish, loss of 300 MW
B: European, loss of 2500 MW
C: European, loss of 1200 MW

Irish Experience

SEI Sustainable Energy Ireland

- Irish System Characteristics:
  - Small Size: 5550MW ROI, 1837 NI
  - Tight Capacity Margins, 4568MW Winter Peak ROI
  - Isolated Island System
  - Limited Interconnection: 500MW UK – NI; 300MW NI - ROI
  - Mainly Thermal Generation: 90% ROI
  - Limited Storage: 292MW Pumped Storage Facility

Irish Experience

sei SUSTAINABLE ENERGY IRELAND

- Irish System Characteristics:
  - Small Size: 5550MW ROI, 1837 NI
  - Tight Capacity Margins, 4568MW Winter Peak ROI
  - Isolated Island System
  - Limited Interconnection: 500MW UK – NI; 300MW NI - ROI
  - Mainly Thermal Generation: 90%
  - Limited Storage: 292MW Pumped Storage Facility
- Wind Power Penetration May Rise Dramatically in Short Time
  - Currently 242MW in ROI; 51MW NI
  - 500MW by End 2005
  - + >2000MW with Connection Offers or in Application Queue

Wind Farms in Ireland

- 242MW ROI
  - 217MW Onshore
  - 25MW Offshore
- 51MW NI

Recent Developments

- Grid Code for Wind – Initiated September 2003
- Moratorium on Wind Farm Connection Offers Nov 2003
  - System Stability & Security Concerns
  - Proper Dynamic Models not Provided by Manufacturers
  - Ended October 2004
- Proposed Change to Connection Process to Deal with Applications Queue

System Integration Studies in Ireland

- 1990 ESB CIGRE Report – 7.5% Capacity Penetration Limit
- 2000 IWEA Econnect – 20% Capacity Penetration Feasible
- 2003 CER Garrad Hassan/ESBI "The Impacts of Increased Wind Penetration on the Irish Electricity Systems" - 800MW Feasible w/o System Reinforcement
- 2004 ESBNG Report "Impact on Wind Power Generation in Ireland on the Operation of Conventional Plant" Wind CO_2 Abatement Cost €120/Tonne
- 2004 SEI ILEX/UMIST/UCD/QUB Report "Operating Reserve Requirements as Wind Power Penetration Increases in the Irish Electricity System"
- 2004 SEI Brattle Group Report "Renewable Energy in the New Irish Electricity Market"
- 2004 IWEA Milborrow/Duggan Report

Key Issue

- System Capacity to Absorb Intermittent Non-Despatchable Generation – Now and in the Future
- Methodologies:
  - What are the Key Components
  - Are the Studies System Specific
  - What is the Current State of the Art
- How will these Studies be Applied
  - System Adequacy Methodologies
  - Planning of Future Optimal Generation Mix
  - Planning Future System Operation
  - Transmission System Planning

Secondary Studies

- Market Interaction
- Portfolio Optimisation
  - e.g. Wind-Hydro Interaction
- Investigation of Influence of Key Technical Issues
  - Forecast Accuracy
  - Influence of Fault Ride Through Capability
  - Ancillary Services Delivery
  - Dynamic Model Accuracy

Why Propose IEA Annex on System Studies?

SEI SUSTAINABLE ENERGY IRELAND

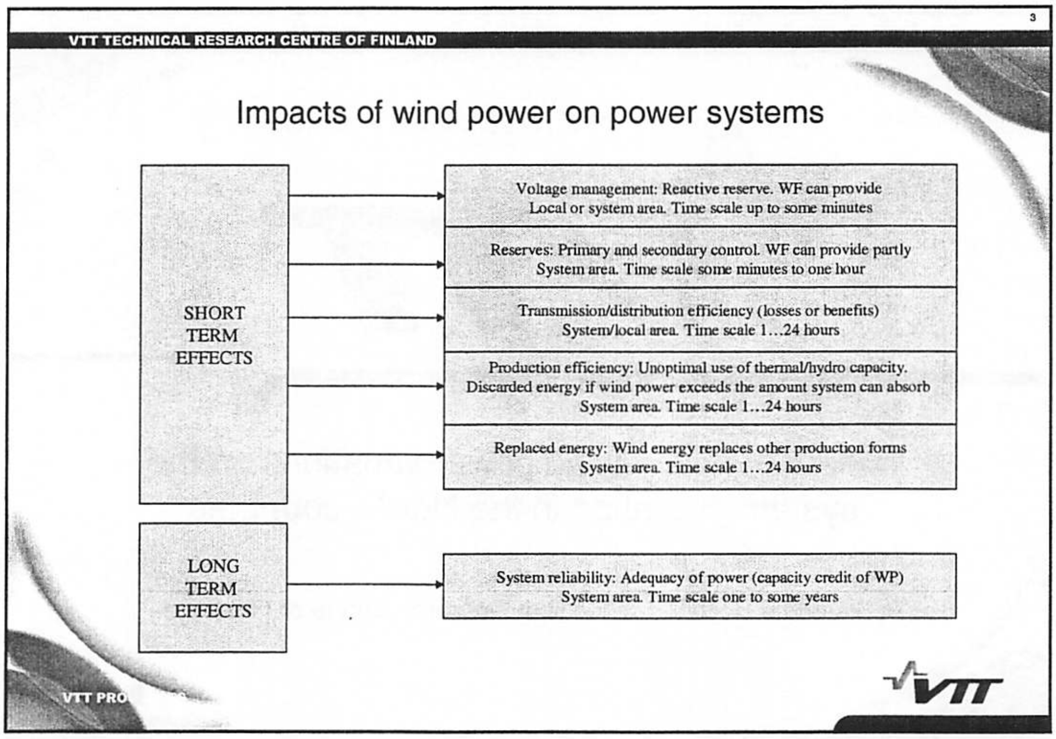
- Such Studies Often Influence Policy at National Level
- Important that Correct Methodologies are Used
- Definition & Refining of Methodologies Required
  - New Approaches Evolving
    - Generation of Wind Power Time Series from Limited Data Set
  - Relative Importance of Study Components According to System Type
- IEA R&D Wind Could Define Standard for Such Studies
  - In Co-Operation with CIGRE, UWIG etc?

Impact of hourly wind power variations on the system operation in the Nordic countries

Hannele Holttinen, Technical Research Centre of Finland

Contents

- Impacts of wind power on the electricity system
  - previous work, main results
- Large scale wind power production and smoothing effect
- Primary reserve requirement due to wind power
- Secondary reserve requirement due to wind power
- Discussion


VTT TECHNICAL RESEARCH CENTRE OF FINLAND
3
Impacts of wind power on power systems
SHORT TERM EFFECTS
Voltage management: Reactive reserve. WF can provide
Local or system area. Time scale up to some minutes
Reserves: Primary and secondary control. WF can provide partly
System area. Time scale some minutes to one hour
Transmission/distribution efficiency (losses or benefits)
System/local area. Time scale 1...24 hours
Production efficiency: Unoptimal use of thermal/hydro capacity.
Discarded energy if wind power exceeds the amount system can absorb
System area. Time scale 1...24 hours
Replaced energy: Wind energy replaces other production forms
System area. Time scale 1...24 hours
LONG TERM EFFECTS
System reliability: Adequacy of power (capacity credit of WP)
System area. Time scale one to some years
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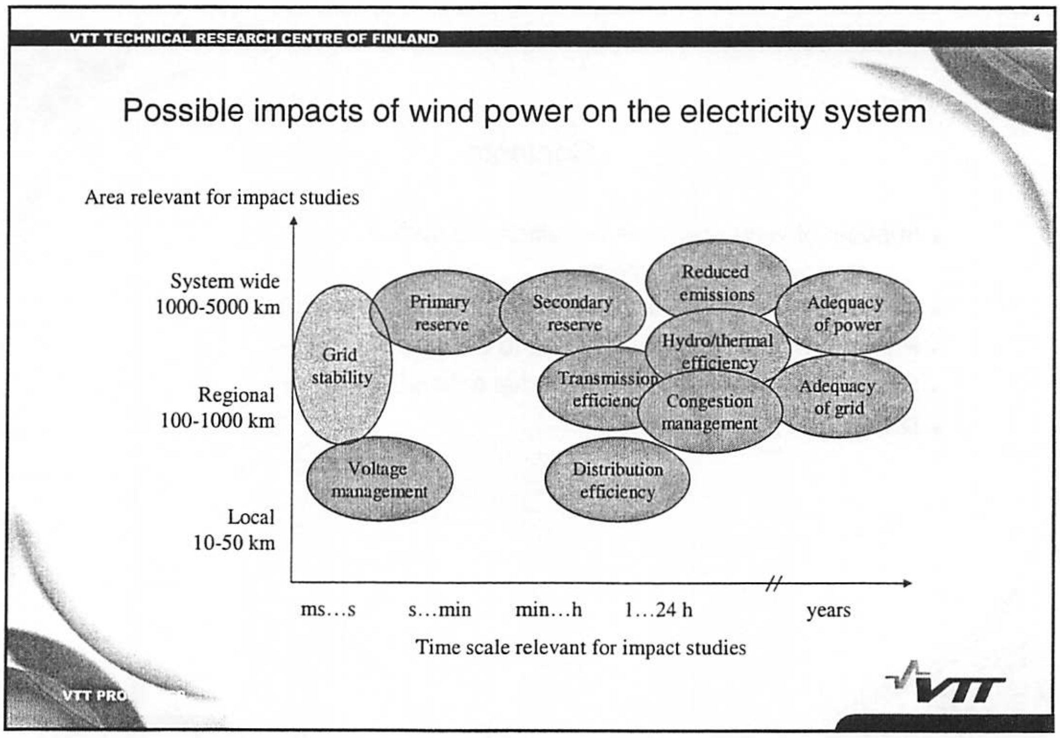
VTT TECHNICAL RESEARCH CENTRE OF FINLAND
4
Possible impacts of wind power on the electricity system
Area relevant for impact studies
System wide
1000-5000 km
Regional
100-1000 km
Local
10-50 km
Grid stability
Primary reserve
Secondary reserve
Reduced emissions
Adequacy of power
Hydro/thermal efficiency
Transmission efficiency
Congestion management
Adequacy of grid
Voltage management
Distribution efficiency
ms...s
s...min
min...h
1...24 h
years
Time scale relevant for impact studies
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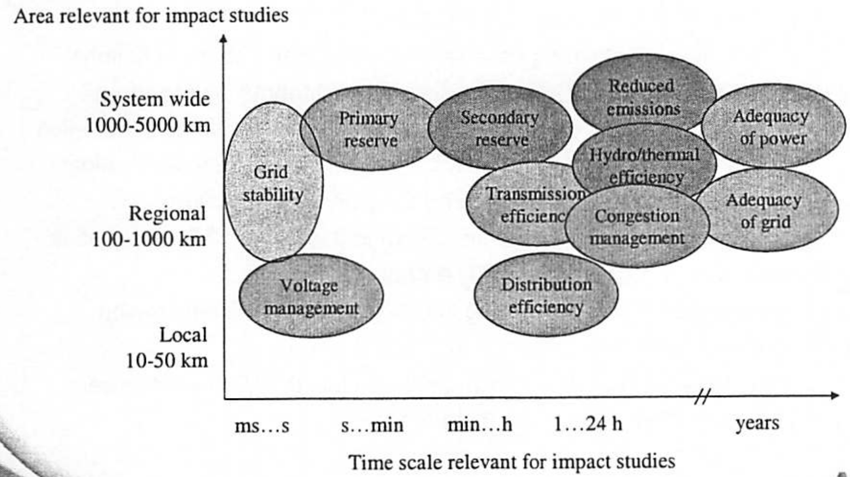
5

Possible impacts of wind power on the electricity system



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Previous work – some results

- Primary reserves:
  - no impact in reasonable penetration levels; wind farms can provide
- Secondary reserves: increasing impact with increasing penetration
  - 1...2 €/MWh at 10 % and 2...5 €/MWh at 20 % penetration
- Transmission and distribution losses and congestion management
  - reduction or increase depending on the siting of wind power vs load
  - high penetration of wind power → an increase in transmission is seen
- Efficiency of production in the electricity system
  - Losses in efficiency of thermal/hydro power plants
  - Discarded wind energy, starts at 10 % penetration if thermal system leaves turbines on-line for reserves
- Adequacy of power system
  - capacity credit of wind power near average production when small penetration, reducing at higher penetrations

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Impacts of wind power on the Nordic electricity system - main results of PhD study

- Large-scale wind power production
  - smoothing effect strong especially for in-hour and hourly variations
- Increased requirements for secondary, load following reserves
  - 310-420 MW (2 % of capacity), 1 €/MWh for 10 % energy penetration
  - 1200-1400 MW (3-4 % of capacity), 2 €/MWh for 20 % penetration
- Wind power increases losses in hydro power production
  - of the order of 1 % of the produced wind energy, at 12 % penetration
- Wind power decreases the CO_2 emissions
  - initially 700 g/kWh decreasing to 620 g/kWh at 12 % penetration
- Wind power affects the electricity market prices:
  - decrease of spot market price, 2 €/MWh for 10 TWh/a wind power
  - increase of regulation power market price

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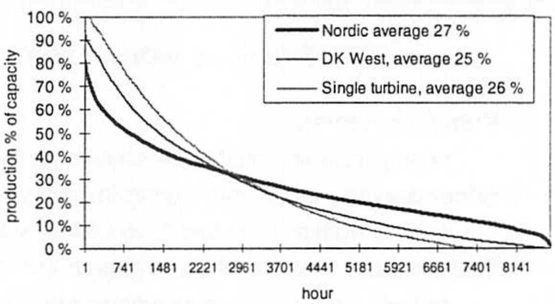
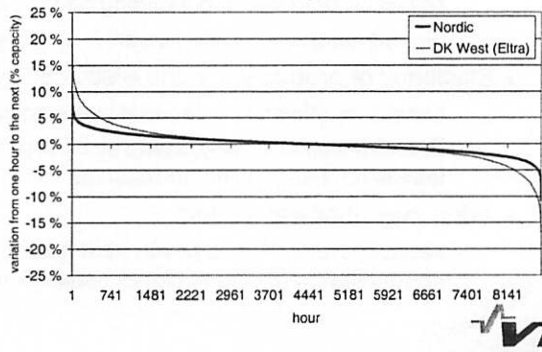
Smoothing effect

- Large-scale wind power: thousands of turbines, hundreds of sites
- Production below 5 % or above 70 % of installed capacity rare
- Hourly step changes: 99 % of the time between ± 10 % of capacity (FI, DK) and 98 % of the time between ± 5 % of capacity (Nordic)





9

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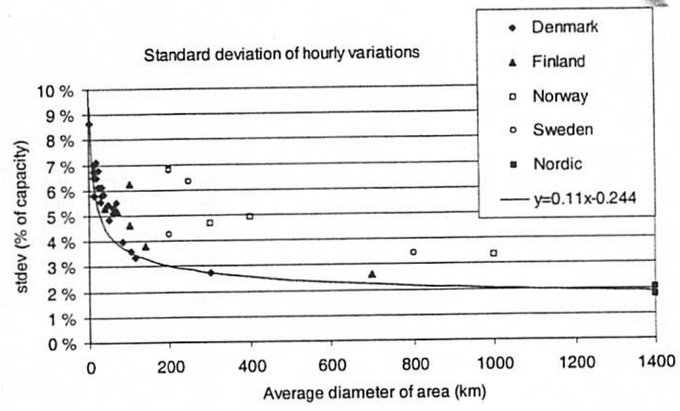
Representativity of input wind data (the smoothing effect)

- After the smoothing effect reaches saturation, it is ok to up-scale the data
- Clearest indication of smoothing effect in the data: stdev of time series for hourly variations
- Finland and Nordic data sets representative, Norway and Sweden not



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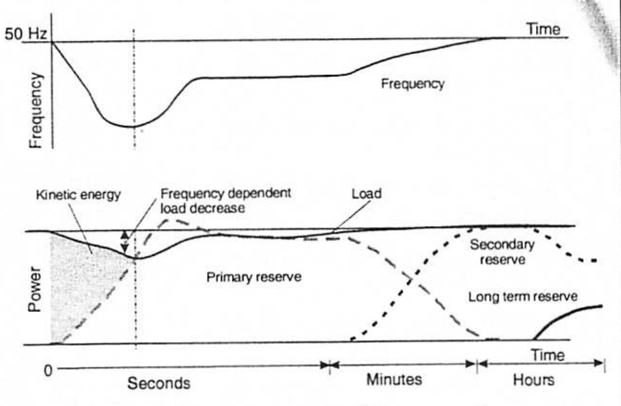
Increased reserve requirement due to wind power

- Study area: synchronous power system, in case of bottlenecks part of the area
- Study time scale: primary reserve (regulation): 1 s...1 min, secondary reserve (load following): 10 min...1 hour
- Wind power only affects the operational reserve, the largest wind farms are less than the largest unit (1200 MW in the Nordic system) dimensioning the disturbance reserve
- Incremental increase due to wind: net balance for the power system



Activation of power reserves and frequency of power system as a function of time when a large power plant is disconnected from the power system

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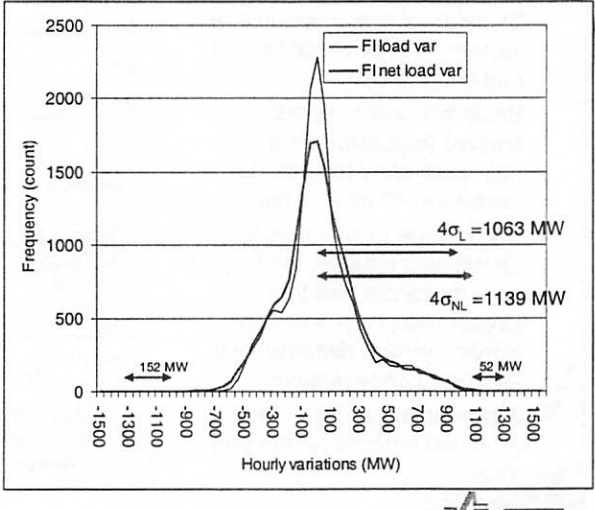
Primary reserve requirements for wind power

- Wind power variations on time scale seconds to 1 minute do not correlate for large scale wind power → output smoothed out
- A rough estimate for the order of magnitude:
  - how much primary reserve in the system for the varying load: 600 MW in Nordel synchronous system for 360 TWh/a load
  - assumption: increasing wind power has same effect as increasing load → 10 % wind power would require 60 MW increase in reserve
  - cost for reserve: 3.3 €/MWh + fixed 7500 € per MW → 60 MW for 36 TWh wind results in less than 0.1 €/MWh

Secondary reserve requirements for wind power (1)

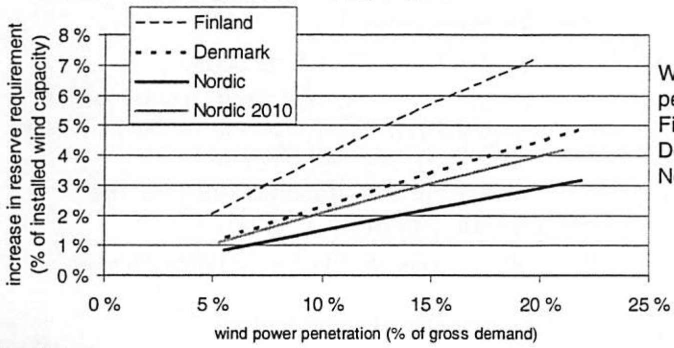
- Wind power variations in time-scale 15 min…1 hour
  - σ for time series of hourly variations 2…3 % of installed capacity
- System will see the aggregated net imbalance
  - unforeseen variations from load and wind
  - net load is load – wind power: $\sigma_{NL} = \sigma_L + \sigma_W$
  - confidence level 4σ used to cover variations → increase in reserve requirement is $4(\sigma_{NL} - \sigma_L)$



13

Secondary reserve requirements for wind power (2)

- Using the time series of (hourly) variations does not take into account that the load time series is more predictable than wind power
  - Case Finland 2001 : using load prediction decreases the σ_L to about half, so the increase in reserve requirement is double the amount estimated by simple $4(\sigma_{NL} - \sigma_L)$



Wind power at 10 % penetration of gross demand:
Finland: 4000 MW, 8 TWh/a
Denmark 2000 MW, 4 TWh/a
Nordic 19000 MW, 40 TWh/a

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Cost of secondary reserve requirements for wind power

- Increasing effect with increasing wind power penetration
  - How much: depends on the level of initial load variations as well as the size of the area and how dispersed the wind power is
  - How costly: depends on the available flexibility in the system and cost of new flexibility (hydro power, demand-side-management, ...)
- Cost of new reserve capacity for the Nordic countries
  - Estimated increase in largest variations 310-420 MW for 10 % energy penetration and 1200-1400 MW for 20 % penetration
  - Example, new NGCC capacity built, **0.5...0.7 €/MWh at 10 % penetration** and 1.0...1.3 €/MWh at 20 % penetration
- Cost of using the reserve capacity more for the Nordic countries
  - Estimated increase 0.7 TWh/a at 10 % ; 2.3 TWh/a at 20 % penetration
  - Realised cost of regulation at the Nordic regulating power market 4...15 €/MWh : **0.1...0.2 €/MWh at 10 % penetration** and 0.2...0.5 €/MWh at 20 % penetration

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Discussion

- Estimates based on synchronous hourly data for load and wind
  - 15-min time scale would not result in higher estimates for the reserve requirements, as in-hour variations of wind power less than hourly
- Cost estimate for the increase in reserve capacity conservative
  - wind power will affect the price level of the regulating power market, but probably not on new capacity built
- Forecast errors of wind power on 2…36 h time scale
  - can affect the regulating power market, depending on how much is corrected by the wind power producer/balance responsible players as more accurate closer-to-delivery forecasts show up
- When a 20 % wind power energy penetration is reached, the power system will probably be different:
  - power produced for vehicles used for about 1000 hours per year

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Licenciate thesis, and soon PhD to be found at

http://www.vtt.fi/renewables/windenergy/

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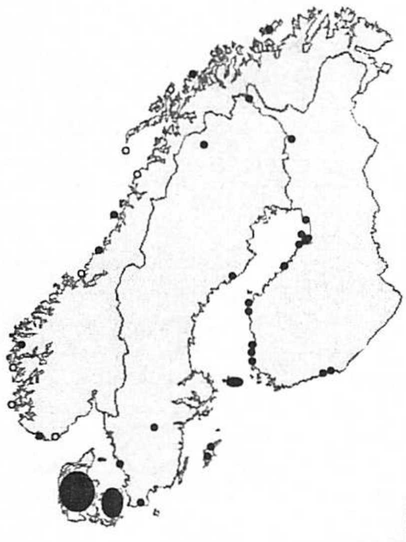
Data for wind power production

- 21 sites in Finland
- 6 sites in Sweden
- 6-12 sites in Norway (the lighter coloured sites only for part of the time)
- aggregated total production of hundreds of sites in Denmark West and East.



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Secondary reserve requirements for wind power (2)

- Using 4σ for the time series of (hourly) variations does not account for that the load time series more predictable than wind power
  - Case Finland 2001 load prediction: using load prediction decreases the σ_L to about half, so the increase in reserve requirement is double the amount estimated by simple $4(\sigma_{NL} - \sigma_L)$

	Finland		Denmark		Nordic	
	MW	% of peak	MW	% of peak	MW	% of peak
Stdev of load variations*	268	2.0 %	273	4.3 %	1438	2.1 %
Stdev of wind variations*		2.6 %		2.9 %		1.8 %
Increase in variations, 10 % penetration	80	2.0 %	24	1.2 %	155-210	0.8-1.1 %
Increase in variations, 20 % penetration	285	3.6 %	94	2.4 %	600-800	1.6-2.1 %
Increase in reserve, 10 % penetration	160	3.9 %	50	2.5 %	310-420	1.6-2.2 %
Increase in reserve, 20 % penetration	570	7.2 %	200	4.9 %	1200-1400	3.1-4.2 %
Wind power at 10 % penetration	4000	8 TWh/a	2000	4 TWh/a	19 000	40 TWh/a

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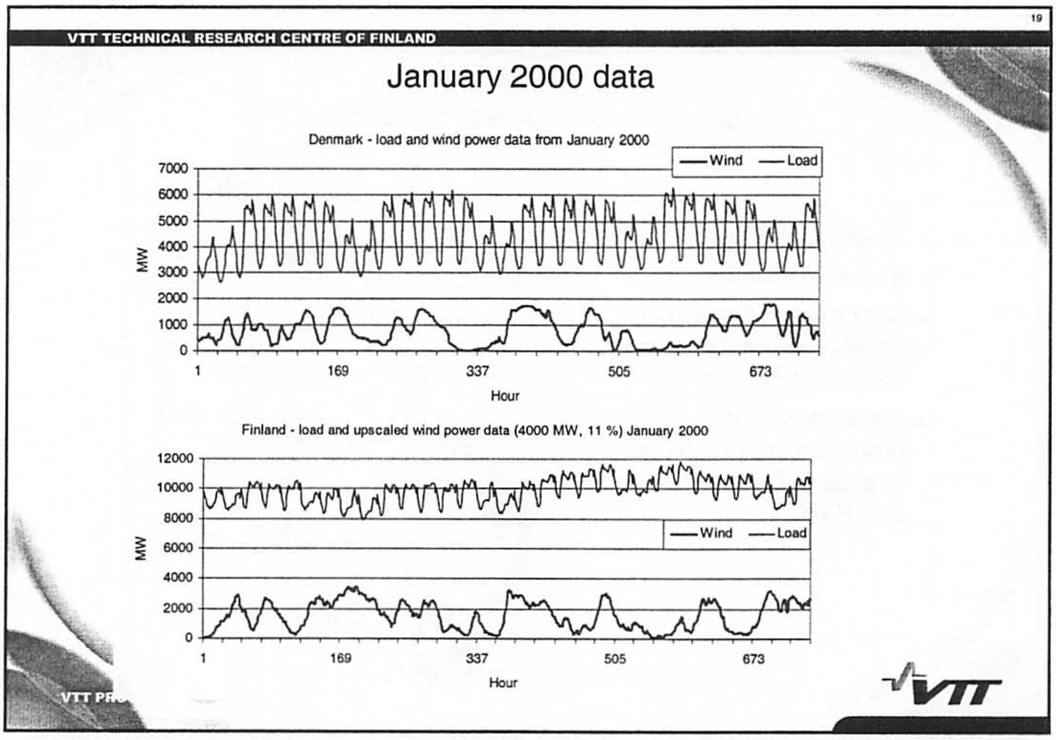
19
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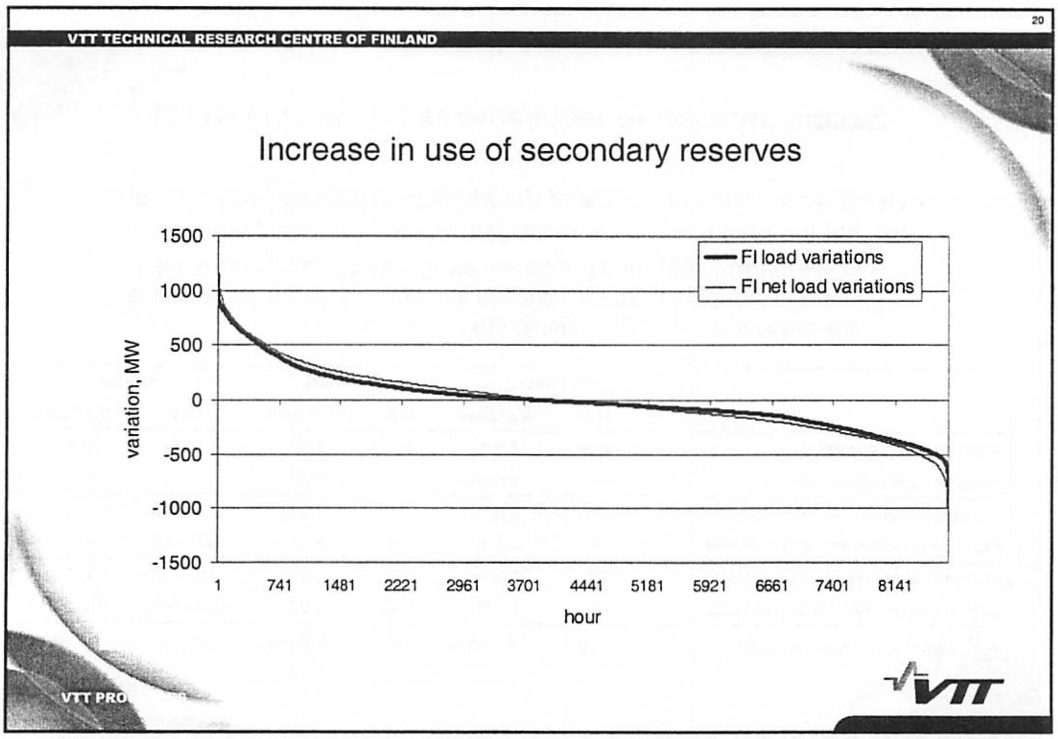
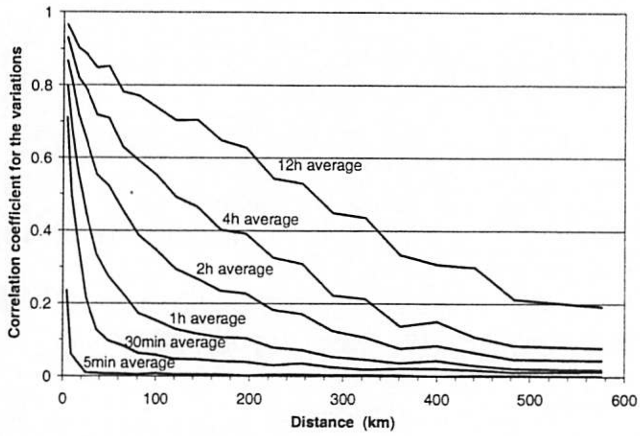
January 2000 data
Denmark - load and wind power data from January 2000
Wind
Load
7000
6000
5000
4000
3000
2000
1000
0
MW
1
169
337
505
673
Hour
Finland - load and upscaled wind power data (4000 MW, 11 %) January 2000
12000
10000
8000
6000
4000
2000
0
MW
Wind
Load
1
169
337
505
673
Hour
VTT


20
VTT TECHNICAL RESEARCH CENTRE OF FINLAND
Increase in use of secondary reserves
FI load variations
FI net load variations
1500
1000
500
0
-500
-1000
-1500
variation, MW
1
741
1481
2221
2961
3701
4441
5181
5921
6661
7401
8141
hour
VTT

Correlation of the variations of wind power production



Source: Ernst, 1999 (German data, ISET)

Ideas for new Annex – System integration

- Scope: the impacts that require system-wide analyses
  - Leave out impacts that are dealt with locally: distribution efficiency, voltage management (?)
- Goals:
  - State-of-the art: research made so far
  - Guidelines for the study methods and data used for impacts of wind power
    - How to incorporate wind power in the energy system planning models (uncertainty in different time scales)
  - Consensus of the group: quantifying what are the impacts of wind power on power system and what are the costs associated (range for different systems)
  - Information exchange

System integration of wind power – New Annex

- Time schedule:
  - plan to be presented for ExCo May 2005
  - start work September 2005...January 2006
  - 3 years
- Coordination costs of operating agent:
  - Total 84 000 euro for 3 years, 28 000 euro/year
    - Meetings, administration: 3 man-months (1 man-month/year)
    - Reporting: 3 man-months
    - Travel costs 12 000 euro total (4000 euro/year)
- Cost of participating, if 6...10 participating countries
  - Yearly cost 2800...4700 euro/participant
  - Total cost 8400...14000 euro/participant

RISØ

System integration of wind turbines in Denmark

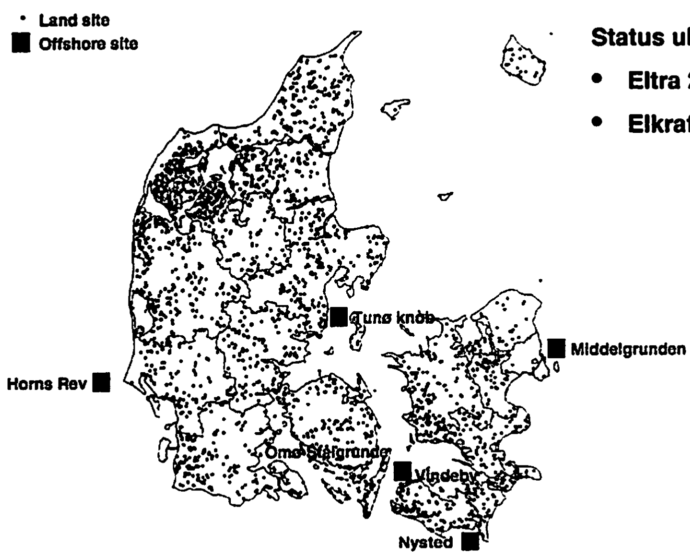
Poul Sørensen

Wind Energy Department

Risø National Laboratory

RISØ

Wind turbine sites



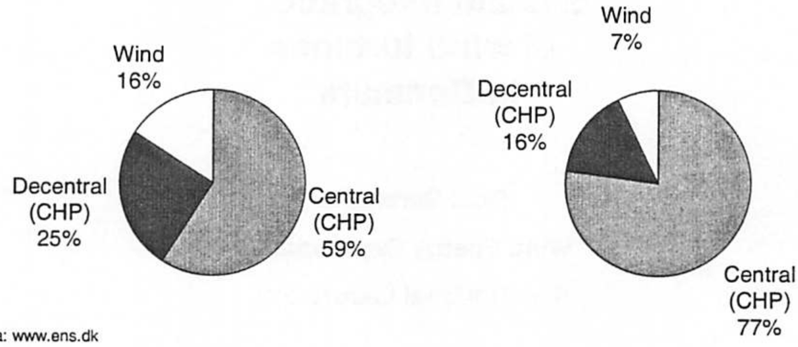
Status ultimo 2003:

- **Eltra 2400 MW**
- **Elkraft 743 MW**

Capacity and production / west and east

RISØ

- **Installed wind power ult. 2003:**
  - 2400 MW
- **Installed wind power ult. 2003:**
  - 743 MW



Data: www.ens.dk

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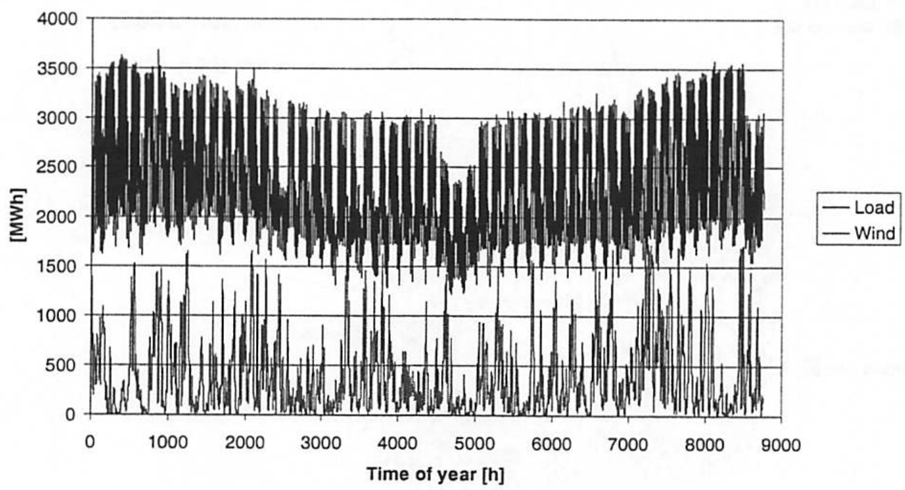
Eltra wind power and load 2001

RISØ



Data: www.eltra.dk

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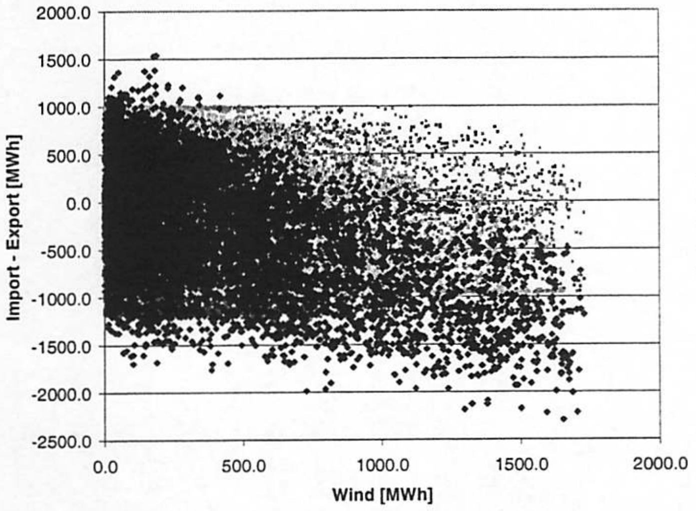
Eltra export / import 2001

RISØ



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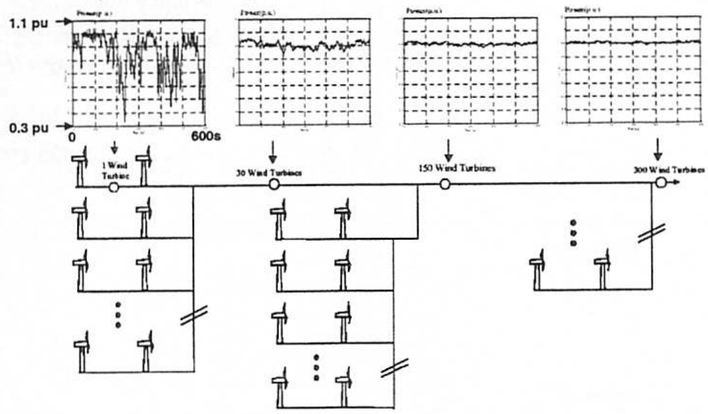
Wind farm smoothing effect

RISØ

- Simulated smoothing of wind farm power
- Kaimal spectrum (only turbulence fluctuations) used as input



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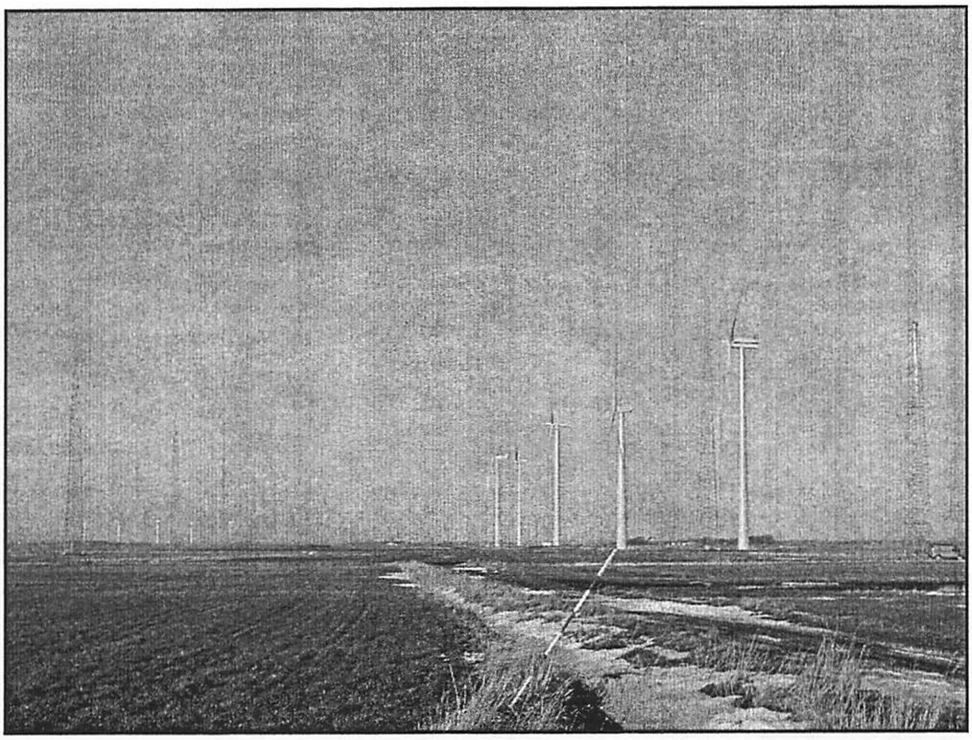
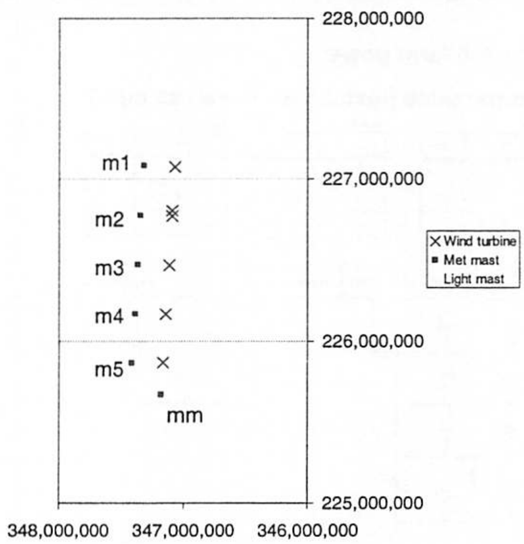


Positions of masts and wind turbines

RISØ



- 5 wind turbine measurement masts
- Distance 300 m
- 2003-07-24 to 2003-31-10 m1-m5 80 m height (m1 78m)
- After 2003-11-13: m1 100m, m3 out, mm 80m)

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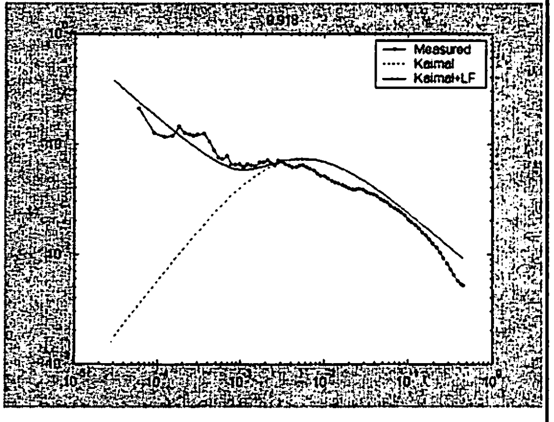
Below-turbulence wind fluctuations

RISØ

- Kaimal spectrum and similar uses in structural design
- Significant fluctuations in "below-minute-range" not included in these spectra
- Spectral shape in the "below-minute-range" estimated based on Høvsøre measurements
- Coherence is also studied



"Old" power quality requirements

RISØ

- KR77 (1984)
  - LV and MV (10-20 kV) connections
  - max cutin currents = rated generator current
  - max 1% voltage increase (MV connections)
- KR100
  - Small adjustments of voltage increase requirements
- IEC 61400-21 (2000)
  - measurement and assessment of power quality: max power, reactive power, flicker, harmonics
- KR111
  - requirements based on IEC 61400-21

"New" system requirements (grid codes)

RISØ

- Specifications for connecting wind farms to the transmission grid (FE 1999 [DK], SE 2000 [DK/EN])
- Requirements for wind turbines connected to voltage below 100kV (May 2004)
- DRAFT Requirements for wind farms connected to voltage above 100kV (Sep 2004, in hearing)

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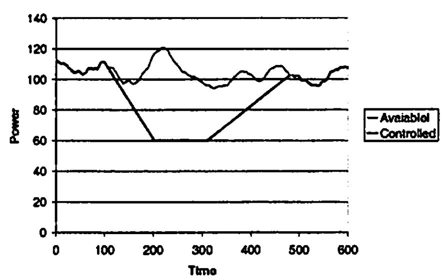
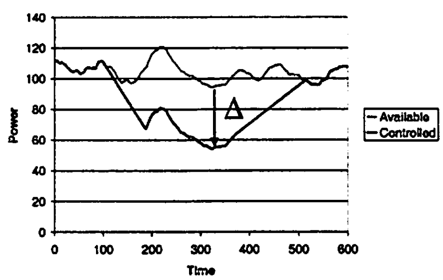
Power control

RISØ

- Balance control
- Ramp limitation



- Delta control
- Ramp limitation



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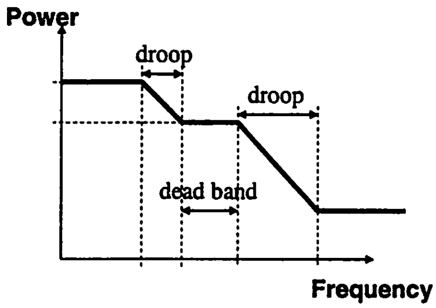
Frequency control

RISØ

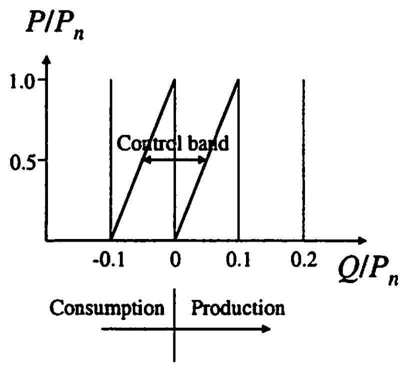
- **Eltra/Elkraft 2000 transmissionssystem:**
  - isolation from large grid: dead band and droop
  - primarily power reduction
  - few seconds response
- **Eltra/Elkraft 2004 <100kV:**
  - as above, more detailed description
  - 10% P_n pr. sekund
- **Eltra/Elkraft 2004 >100kV (DRAFT):**
  - + park control
  - + system protection



Voltage control

RISØ

- **2000:**
  - Unity power factor
  - If more control possible, must be available to operator
- **2004**
  - More specific minimum requirement (figure control band)
  - Control modes (if possible)
    - Mvar control
    - Voltage control (park level)
    - Minimum requirement (as in figure)



Designing voltages and frequencies

RISØ

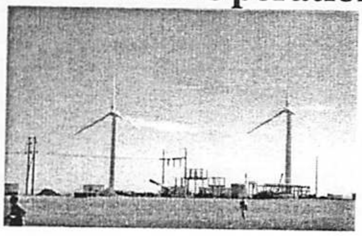
- **Operation in limited period with abnormal voltage or frequency required**
- **Power reduction accepted for abnormal frequencies**
- **Must disconnect at a certain level.**

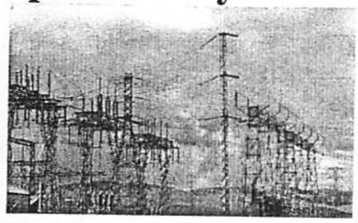
Fault ride through

RISØ

- **Wind turbines have to stay connected:**
- **Test method**
  - simulation models (have been required since 1999)
    - simulation of given profiles for wind turbine incl stepup transformer connected to Thevenin equivalent with voltage profile (2004)
  - measurement verification
    - registration equipment –10 s > +60s (2000)
    - owner logs (in wind turbines): rotor speed, active and reactive power (generator) and voltage (2004 specification)
    - TSO logs (in PCC): voltage, active and reactive, frequency, current, harmonics (2004 specification)

U.S and DOE/NREL Activities in Grid Integration and Operational Impacts Analysis





Brian Parsons
and Jack Cadogan
National Renewable Energy Laboratory
and U.S. Department of Energy Wind Program

IEA Topical Experts Meeting
System Integration of Wind Farms
at Jurys Hotel
Dublin,Ireland

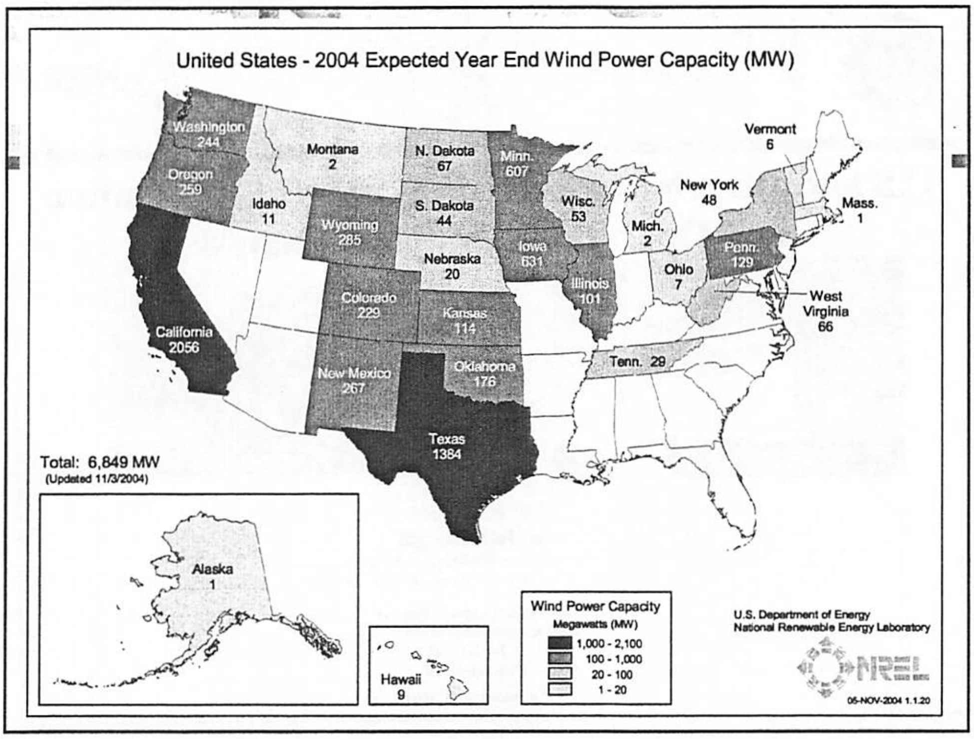
November 9-10, 2004

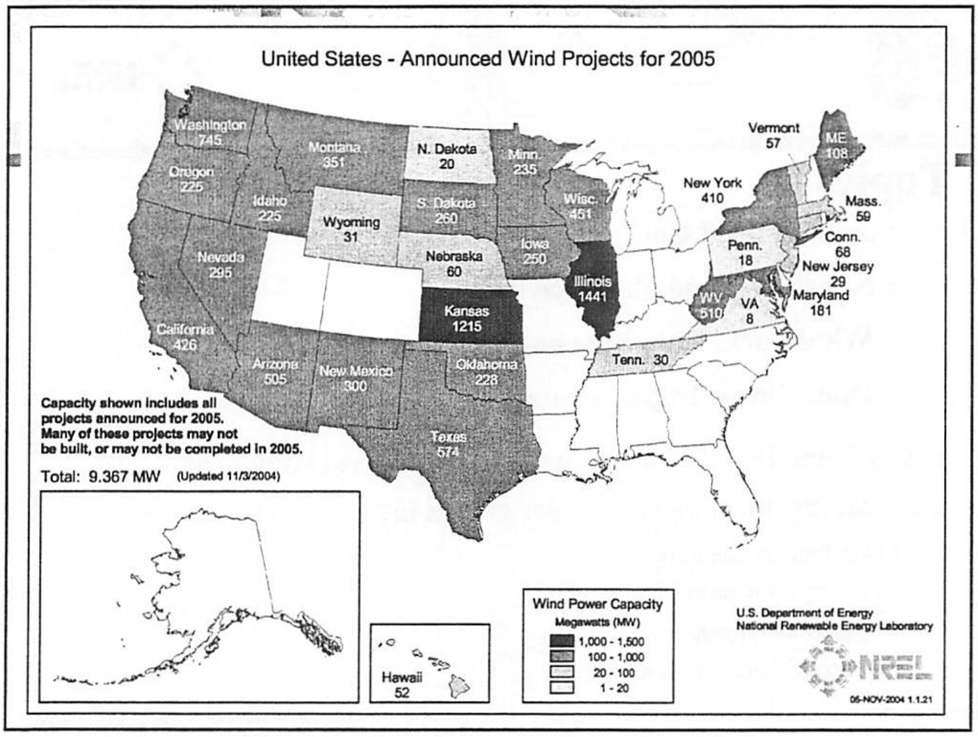
Topics

- **AWEA Grid Code**
- **Select Transmission activities**
- **Wind Farm Data Monitoring**
- **Operational Impacts Analysis**

Utility Wind Interest Group (www.uwig.org) is evolving as the focal organization due to user groups in:

- Distribution line impacts
- Transmission policy and tariffs
- Operational impacts
- Generator/wind farm models


United States - 2004 Expected Year End Wind Power Capacity (MW)
Washington 244
Oregon 259
Idaho 11
Montana 2
Wyoming 285
N. Dakota 67
S. Dakota 44
Nebraska 20
Minn. 607
Iowa 631
Wisc. 53
Illinois 101
Mich. 2
Ohio 7
Colorado 229
Kansas 114
California 2056
New Mexico 267
Oklahoma 176
Texas 1384
Tenn. 29
Penn. 129
West Virginia 66
New York 48
Vermont 6
Mass. 1
Total: 6,849 MW
(Updated 11/3/2004)
Alaska 1
Hawaii 9
Wind Power Capacity
Megawatts (MW)
1,000 - 2,100
100 - 1,000
20 - 100
1 - 20
U.S. Department of Energy
National Renewable Energy Laboratory
NREL
05-NOV-2004 1.1.20


United States - Announced Wind Projects for 2005
Washington 745
Oregon 225
Idaho 225
Montana 351
Wyoming 31
N. Dakota 20
S. Dakota 260
Nebraska 60
Minn. 235
Iowa 250
Wisc. 451
Illinois 1441
Nevada 295
California 426
Arizona 505
New Mexico 300
Kansas 1215
Oklahoma 228
Texas 574
Tenn. 30
WV 510
VA 8
Penn. 18
New York 410
Vermont 57
ME 108
Mass. 59
Conn. 68
New Jersey 29
Maryland 181
Capacity shown includes all projects announced for 2005. Many of these projects may not be built, or may not be completed in 2005.
Total: 9.367 MW (Updated 11/3/2004)
Hawaii 52
Wind Power Capacity
Megawatts (MW)
1,000 - 1,500
100 - 1,000
20 - 100
1 - 20
U.S. Department of Energy
National Renewable Energy Laboratory
NREL
05-NOV-2004 1.1.21

Grid Code for Wind Power

American Wind Energy Association

- What it IS - standards for electrical quality
  - Low Voltage Ride Through
  - Reactive Power
- What it is NOT- Policy on services, costs, capacity contribution
- What else is in it?
  - Call for central clearinghouse for turbine modeling to be used in software for load-flow analyses (Utility Wind Interest Group)
  - SCADA capability for windfarms to allow 2-way communication
  - Front-end interconnection study flexibility (for feasibility study, not system impact or stability studies)

Adopts E.ON Standard for LVRT at Grid Interconnection

American Wind Energy Association

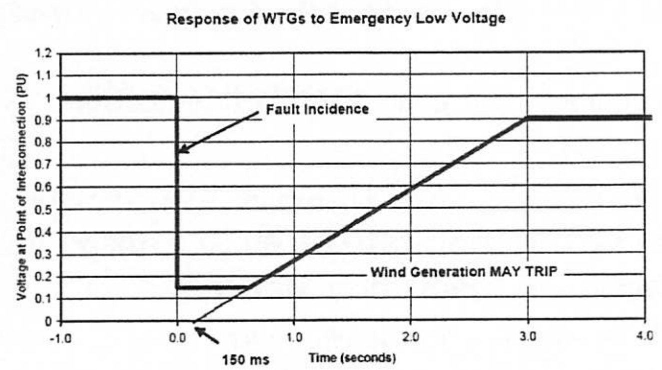


Figure 1 Proposed low-voltage ride through requirement

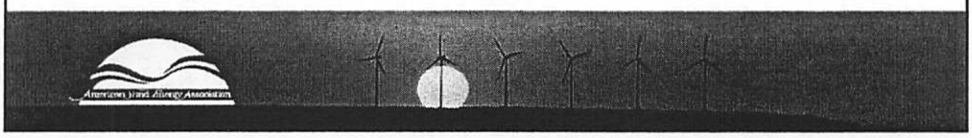
At high side of grid interconnection transformer

American Wind Energy Association

AWEA proposes that a power factor design criteria standard of up to 0.95 leading/lagging be applied to wind plants at the interconnection point (but not necessarily each individual wind generator).

If System Impact Studies demonstrate that reliability criteria are met at less than (closer to unity) 0.95 lagging (capacitive), then that resulting figure becomes the power factor range requirement.

Note that the Western Electric Coordinating Council is proposing a more stringent zero voltage ride thru standard for wind that appears to be difficult for existing conventional synchronous generators to meet



Other Federal Energy Regulatory Commission Activities

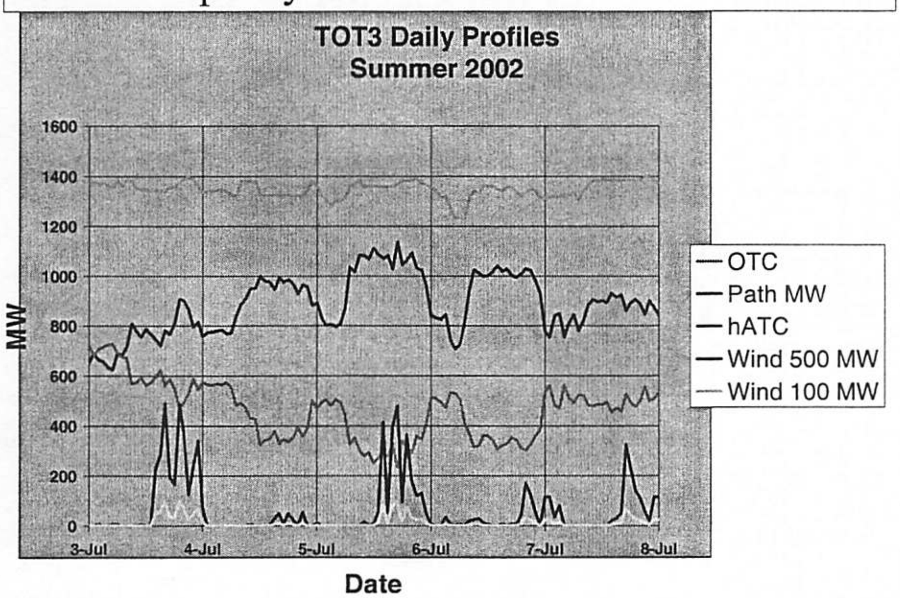
NREL

- Large and small generator interconnection standards
- December 1, Denver Technical Workshop on **Assessing the State of Wind Energy in Wholesale Electricity Markets**
  - Why status quo is not working
  - Planning, forecasting, and grid usage
  - Open Access Transmission Tariff services and pricing

Regional Transmission Expansion Efforts

- Several regional efforts have included 5-10 year wind expansion scenarios
- Need for temporal representation of geographic variability (Mesoscale back-simulation and "virtual" anemometer towers)
- Opportunity for introduction of alternative transmission products (long-term non-firm, or curtailable firm)

Comparison of Available Transmission Line Capacity and Wind Power Profiles

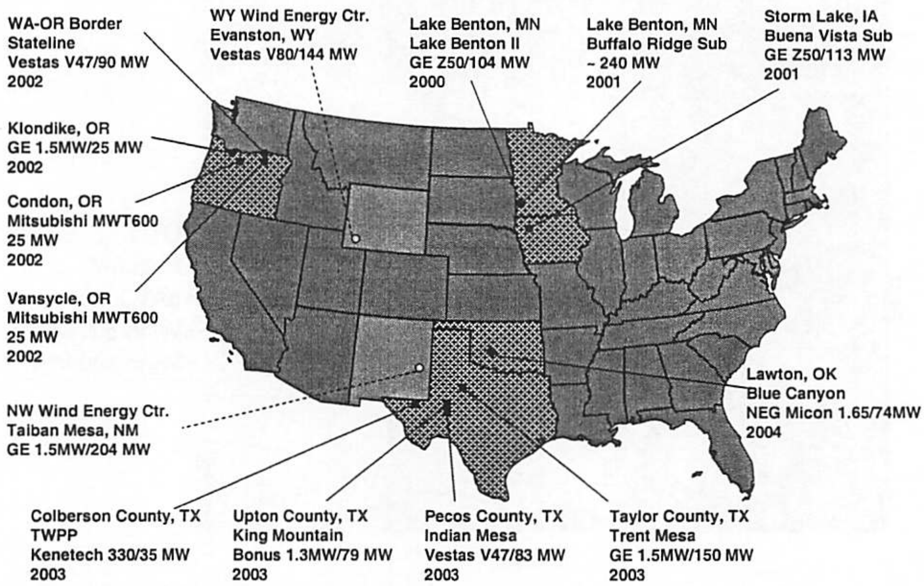


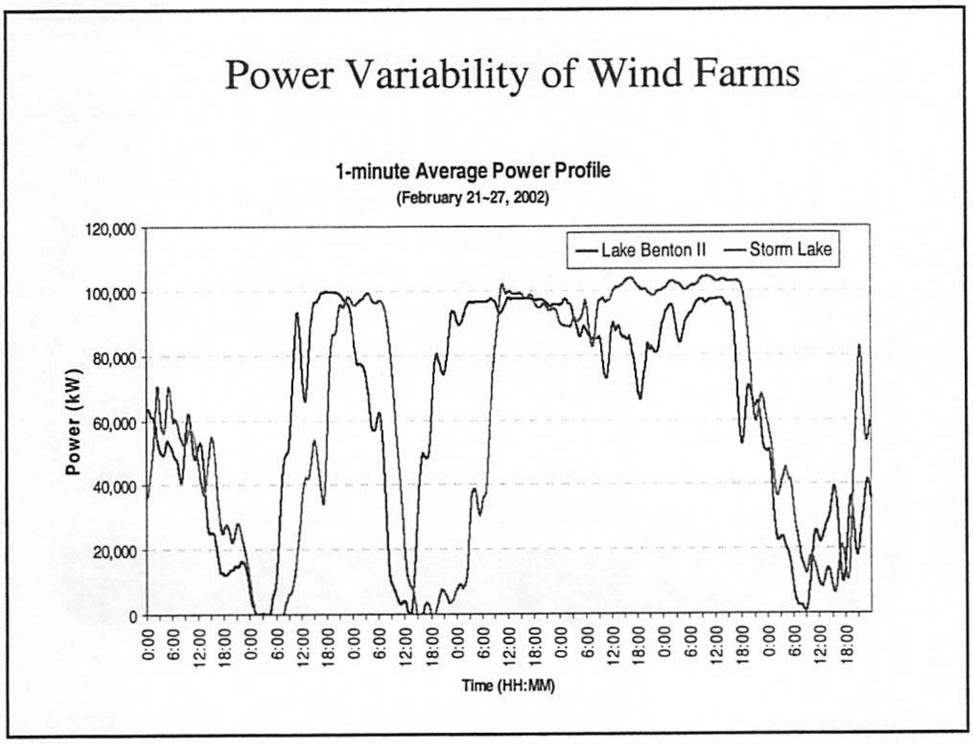
Wind Farm Data Monitoring

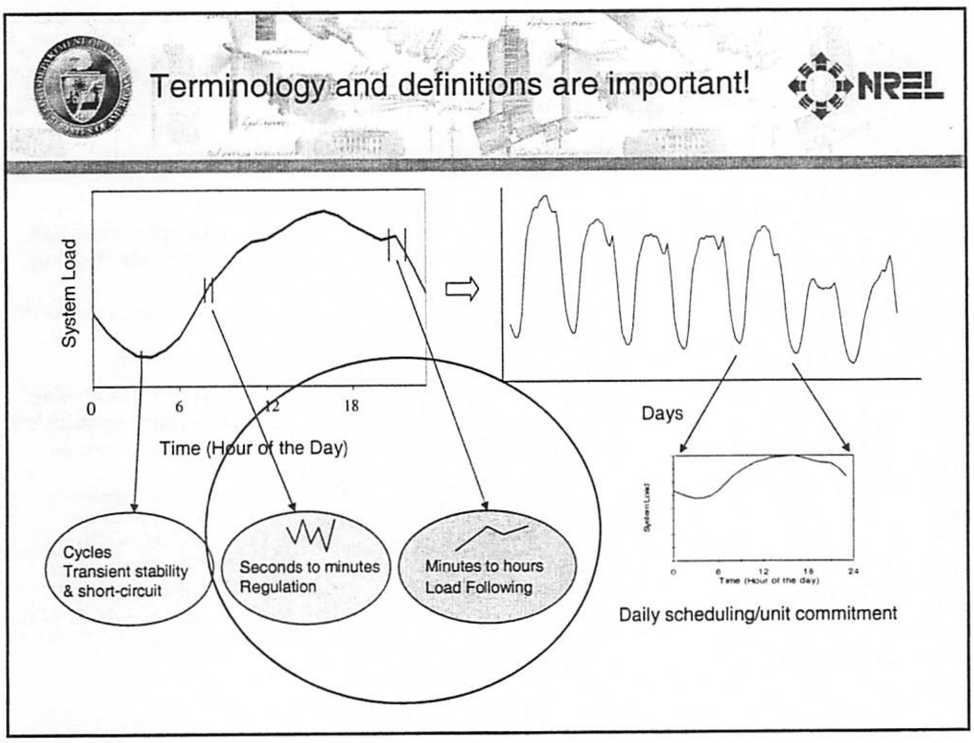
- Real wind farm data needed for dynamic model validation (high-frequency) and system operational studies (long-term)
- Data have been used for
  - methods and analytic studies (ORNL Hirst & Kirby),
  - operating impact studies (UWIG, EnerNex, etc.), and
  - wind farm output forecasting studies (TrueWind, AWS Scientific, Wind Logics)
- Event-triggered, high-frequency (120 samples/sec), short-duration (10 seconds) voltage and current RMS are being collected at Texas wind farms
- Efforts are underway to record wind farm and individual turbine responses under system fault conditions in Wyoming
- Data are available to third parties on a case-by-case basis subject to consent of our industry partners

Wind Farm Monitoring Project

(Total capacity ~950 MW)



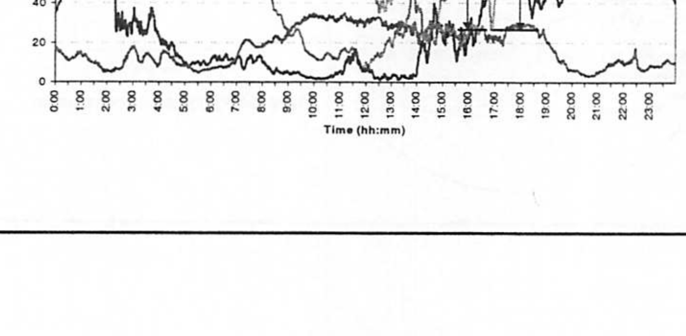

Power Variability of Wind Farms
1-minute Average Power Profile
(February 21~27, 2002)
Lake Benton II
Storm Lake
Power (kW)
120,000
100,000
80,000
60,000
40,000
20,000
0
0:00
6:00
12:00
18:00
Time (HH:MM)


Terminology and definitions are important!
NREL
System Load
0
6
12
18
Time (Hour of the Day)
Days
Cycles
Transient stability
& short-circuit
Seconds to minutes
Regulation
Minutes to hours
Load Following
Daily scheduling/unit commitment

Mitigating Factors

- Actual wind farm power output characteristics
  - Multiple generator smoothing (intra- and inter-site)
  - New generator and farm interface abilities
- Large scale geographic diversity
- *System* characteristics (loads and generators) and statistical, not deterministic nature
- Ability to forecast
- Evolution of competitive wholesale markets (near real time operations and unscheduled deviation practices)

Example Wind Farm Power Data



Example European Grid Code ramping limits:

- 30 MW/min or 100 MW/10 min
- 5% rated/min

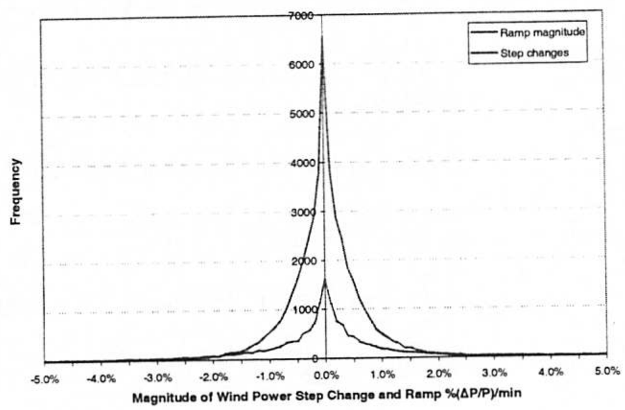
Typical power plant ramping capabilities:

- Hydro 50%~100% per minute
- Combustion turbine 10%~20% per minute
- Coal plant 3%~5% per minute

Load changes:

Standard deviation of 10-min load changes 60 MW (9 GW system)

Step Change and Ramping Rate Distribution



90% of the step changes concentrate in the range of 1% of installed capacity

Ancillary Services Cost Comparison

Study	Relative Wind Penetration (%)	Regulation $/MWh	Load Following $/MWh	Unit Commitment$ /MWh	Total $/MWh
UWIG/Xcel	3.5	0	0.41	1.44	1.85
PacifiCorp	20	N/A	2.50	3.00	5.50
BPA/Hirst	7	0.19	0.28	1.00-1.80	1.47-2.27
PJM/Hirst	0.06-0.12	0.05-0.30	0.70-2.80	N/A	0.75-3.10
We Energies I	4	1.12	0.09	0.69	1.90
We Energies II	29	1.02	0.15	1.75	2.92
Great River Energy I	4.3				3.19
Great River Energy II	16.6				4.53
CA RPS Phase I	5	0.17	0	N/A	0.17
MN DOC/Xcel	15	0.23	0	4.37	4.60

Recent Reports

Xcel Energy and the Minnesota Department of Commerce Wind Integration Study-Final Report
http://www.state.mn.us/mn/externalDocs/Commerce/Wind_Integration_Study_092804022437_WindIntegrationStudyFinal.pdf

Characterizing the Impacts of Significant Wind Generation Facilities on Bulk Power System Operations Planning
http://www.uwig.org/UWIGOpImpactsFinal7-15-03.pdf

Wind Power Impacts on Electric Power System Operating Costs: Summary and Perspective on Work to Date
http://www.nrel.gov/docs/fy04osti/35946.pdf

Wind Power Plant Behaviors: Analyses of Long-Term Wind Power Data
http://www.nrel.gov/docs/fy04osti/36551.pdf

IEA IA R&D Wind Energy

Annex XI meeting
Dublin, 9,10th November 2004

Topical expert meeting on System planning and operation with high wind power penetration

Ana Estanqueiro

TEM on System Operation

IEA IA R,R&D Wind Turbine objectives:

- **Maximize wind power maximum "penetration"**
  - **Without operation or stability problems!!**
- **Select the more adequate methodology to define <u>maximum penetration</u>**
  - **for each grid (or type of grid) and power system**
- **Help the TSO to describe the high wind power penetration scenarios in a realistic manner with technical and scientific accuracy.**

TEM on System Operation

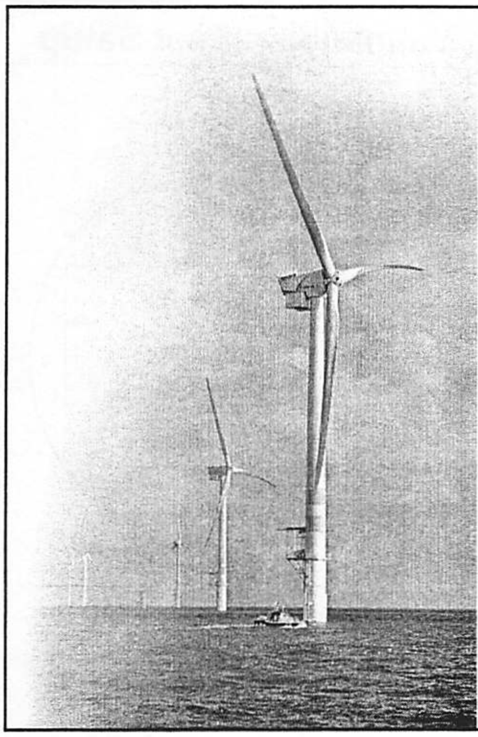
- **What should be addressed:**
  - **Assess the stability of the power system for several scenarios of wind power penetration**
    - **Spatial correlation of wind time series of speed and direction**
      - **Specially for complex terrain countries/areas**
    - **Define the maximum instant power to be expected from the planned wind capacity (with a probabilistic approach)**
  - **Study the system operating reserves**

TEM on System Operation

- **IEA should propose <u>validated models to use in PSS studies</u>**
  - **Or alternatively suggest methods to validate future models**
    - **Currently TSO's are already using non-validated models**
- **IEA may suggest <u>methodologies to be used by TSO planners</u> when studying large scale wind parks grid integration**
  - **E.g: to introduce concepts as "interruption of wind power production" for extreme conditions of the system so the wind power penetration may be maximized**
  - **Minimum impact on most wind park projects economic feasibility**

TEM on System Operation

- **Wind Energy organizations (and specially IEA IA R,D&D WT) shouldn't avoid to face the reality:**
  - Wind power, so far and without storage devices, doesn't give power delivery guarantee;
  - It's a non dispatchable fluctuating source and a "base power production";
  - It's hardly predictable.
- **But there are tools to cope with those limitations:**
  - Assure that power quality parameters are fulfilled so power fluctuations and grid impact are minimum (IEC 61400 – 21);
  - Require wind parks to have (starting yesterday) remote monitoring and operation facilities (future IEC 61400-25 CDV);
  - Every single TSO facing high WP penetration should be carrying out a R&D project for power production prediction



Integration of High Penetration Wind into Electric Power Grids

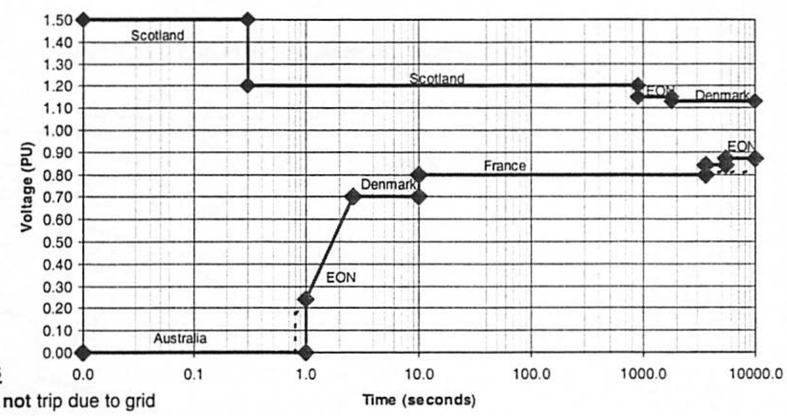
Paul D Hopewell,
GE Energy

IEA - Dublin,
November, 2004

imagination at work

Existing and Anticipated Global Voltage Range

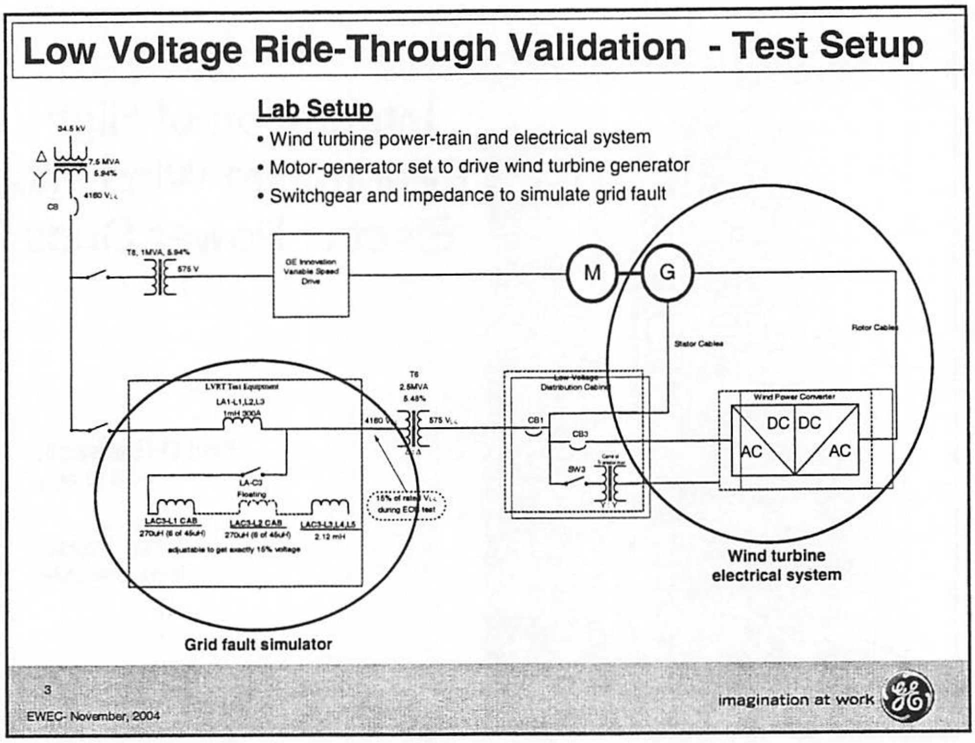
Composite (Worst Case) Emergency Voltage

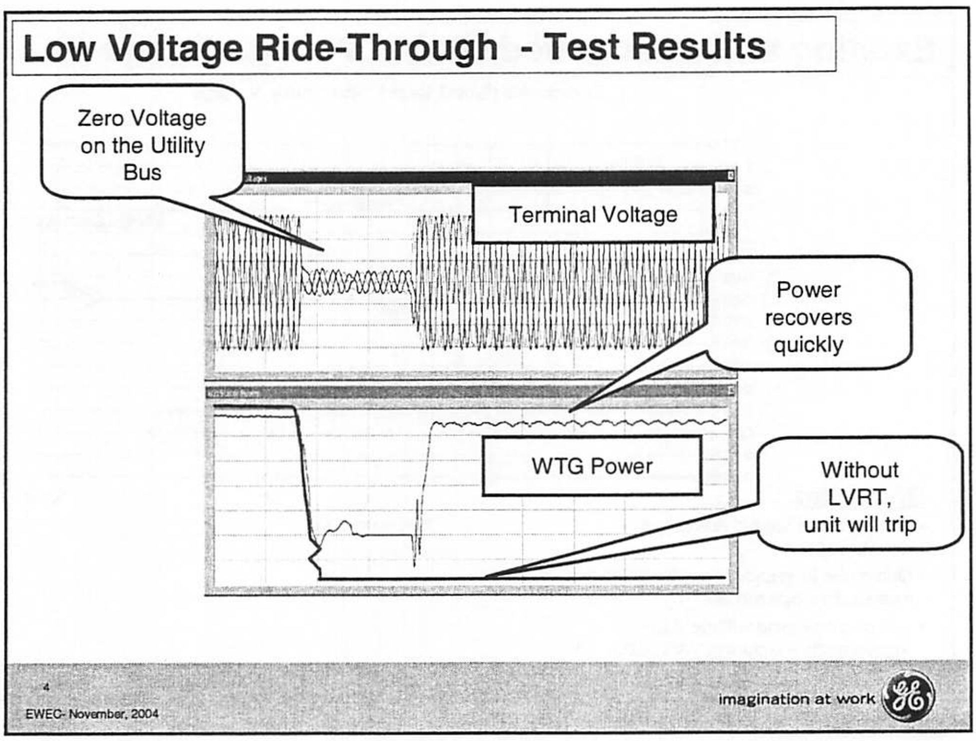


Grid Codes

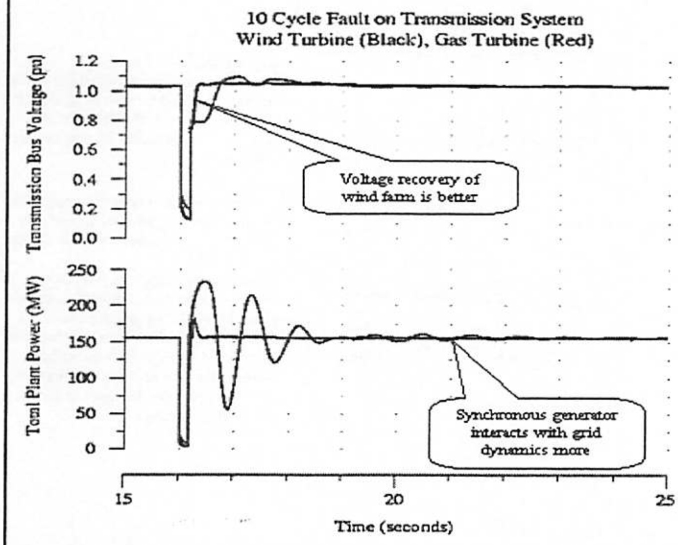
- Turbine **must not** trip due to grid disturbances.
- Grid codes increasingly require LVRT and extended voltage ranges.
- ......plus emerging voltage support requirements – including VArs at zero MW .

imagination at work


Low Voltage Ride-Through Validation - Test Setup
Lab Setup
• Wind turbine power-train and electrical system
• Motor-generator set to drive wind turbine generator
• Switchgear and impedance to simulate grid fault
M
G
DC
DC
AC
AC
Wind turbine
electrical system
Grid fault simulator
3
EWEC- November, 2004
imagination at work


Low Voltage Ride-Through - Test Results
Zero Voltage
on the Utility
Bus
Terminal Voltage
Power
recovers
quickly
WTG Power
Without
LVRT,
unit will trip
4
EWEC- November, 2004
imagination at work

Fault Response – Main Protection Operation



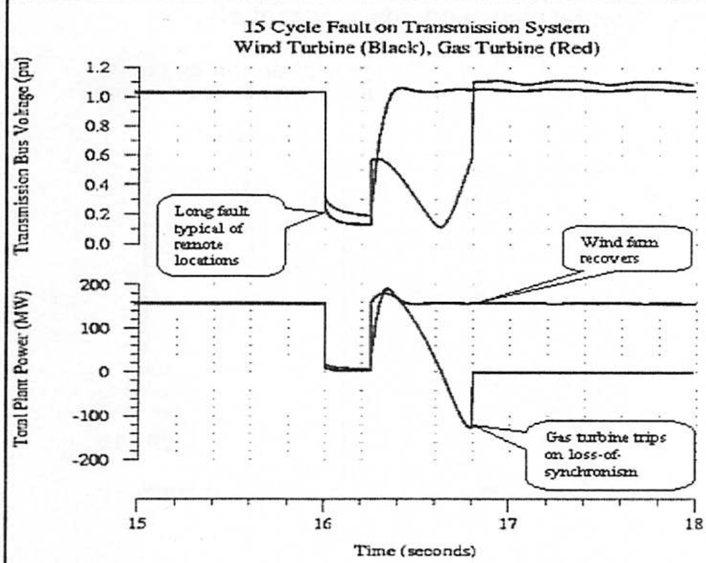
Discussion

Wind turbine response is dominated by power electronic converter behaviour.

Concept of 'rotor swing' is not relevant to the DFIG architecture. Normal operation can be resumed immediately upon fault clearance, with minimal subsequent oscillation.

Synchronous machine response to the same fault is stable, but severe power swings persisting for some seconds longer.

Fault Response – Backup Protection Operation



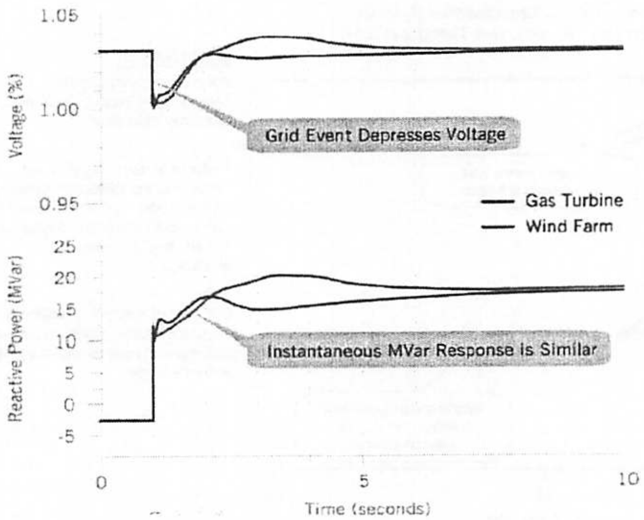
Discussion

For a longer protection clearing period, the wind turbine response is not significantly worse. Wind turbine power output and terminal voltage both recover to pre-fault levels shortly after fault clearance.

Duration of fault now permits the synchronous generator rotor to advance sufficiently to cause pole-slipping. Generator protection system must now trip the generator in order to avoid wild fluctuation of system voltage and possible shaft breakage.

Wind turbine is clearly more robust in dealing with long duration protection operation and fault clearance times.

Response to Transmission Voltage Depression



Discussion

In the event of a distant fault depressing the generator terminal voltage, both the DFIG wind turbine and conventional synchronous generator display similar behaviour.

Each machine attempts to increase its terminal voltage to the target level by injected reactive power into the system.

Since it is dominated by the power converter response, the wind turbine is able to achieve the target voltage somewhat faster than the synchronous machine. However, in this example, there is little practical significance and both machines can be seen to give acceptable response.

7
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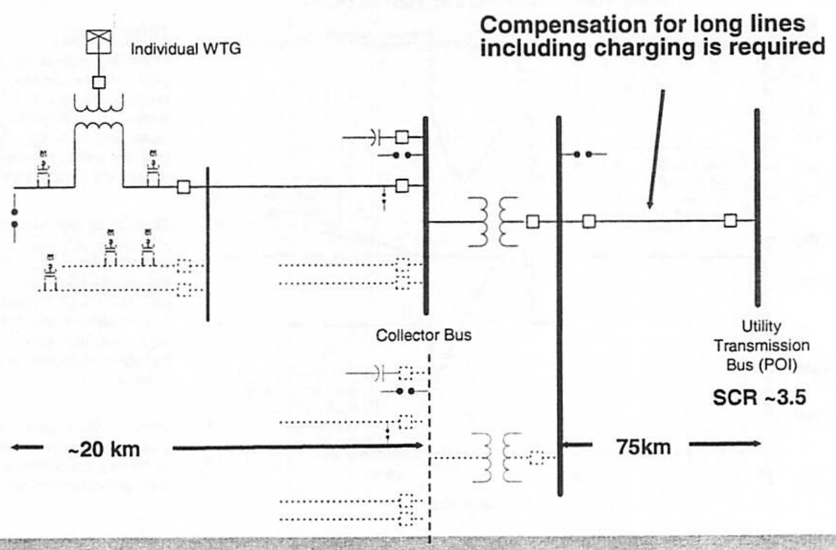
imagination at work

Voltage Regulation at Distant PCC - Layout

Crisp voltage regulation in weak systems is essential



8
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Voltage Regulation at Distant PCC - Performance

Discussion

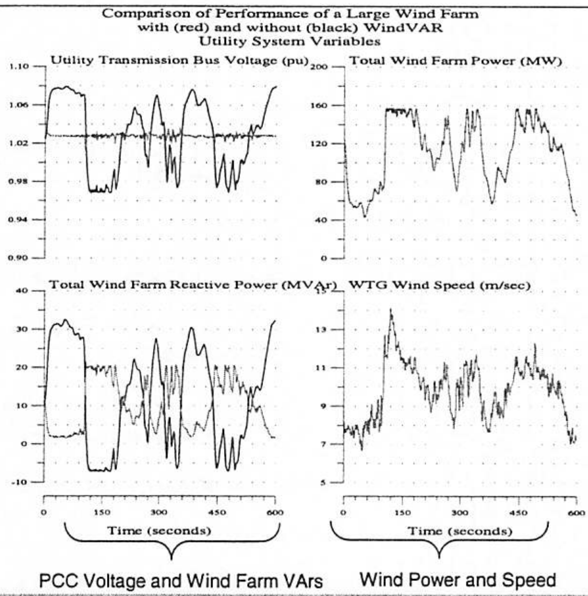
Where the point of common coupling with the host utility is distant, physically and electrically, regulating this voltage can present a considerable challenge. Increased MW export leads to higher MVAr consumption in the interconnection. This additional reactive power may come from either the wind farm, or the host utility.

Wind farms operating at a fixed power factor will not yield the correct MVAr production to hold the PCC voltage constant. This will give highly variable PCC voltage and should not be tolerated.

(black curves)

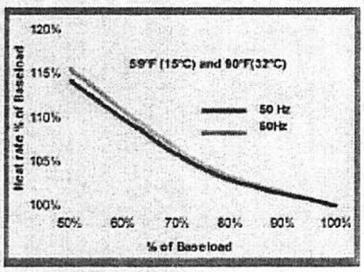
Measuring the PCC voltage and *dispatching* the wind farm MVAr production allows effective voltage regulation. GE WindVAR controller determines farm MVAR schedule and issues wind turbine setpoints. This ensures fast local control in order to a constant voltage at the distant PCC, even in the presence of wind variability.

(red curves)

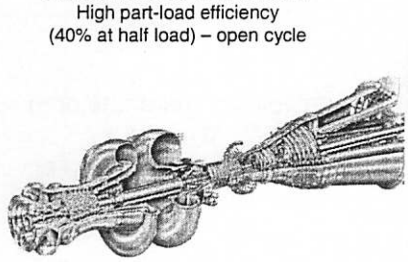


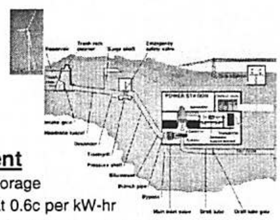
imagination at work

Intermittency Management



GE LMS100 aero-derivative GT.
High part-load efficiency
(40% at half load) – open cycle

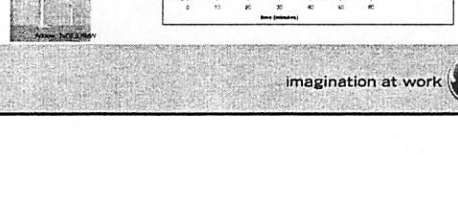




Intermittency Management

- Reservoirs ideal 'virtual' energy storage
- BPA selling wind firming service at 0.6c per kW-hr
- Wind + Hydro power can meet all Canadian energy need
- Norway, New Zealand – similar wind & hydro resources
- Pumped storage excellent, but site constrained
- Part-load GT balancing opportunities

Operate a GT in conjunction with a wind scheme in order to increase dependability of output. Net result is predictable, controllable power to grid and maximum use of wind. GT must have good part-load efficiency and emissions performance.



Associate wind and gas, to give dispatchable resource.

Relative sizes are important.

Dynamic range of GT and relative sizes inter-related.

Use wind ramp-rate limits to 'blunt' edge of GT regulation efforts.

imagination at work

Conclusions

1. Grid Voltage Support is technically feasible using various wind turbine topologies (DFIG, full conversion)

   How can this be best used?

   Can wind farms sell voltage stabilising services?

2. Intermittency Management solutions require energy storage or balancing, controllable generation.

   What must be done to ensure that the combination of wind and balancing generation does not result in increased emissions?

   Is there an optimum mix of market and technological solutions?

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EWEC- November, 2004

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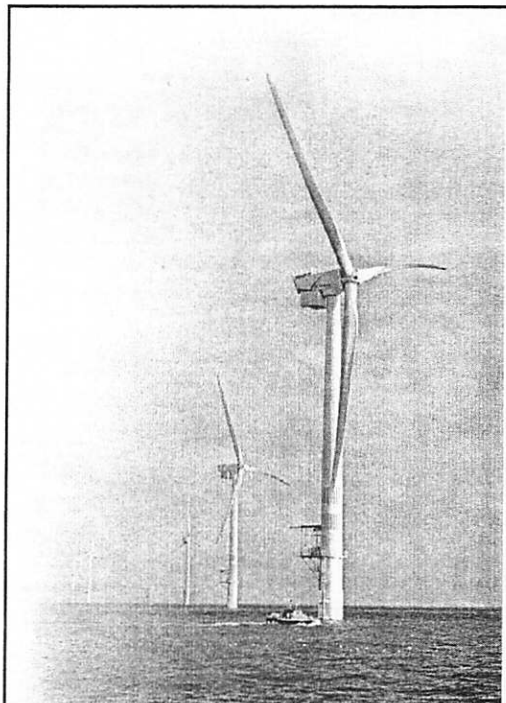


hopewell@research.ge.com

IEA - Dublin,
November, 2004

imagination at work

ECOFYS

Wind farms participating in TSO's Power System Management

IEA Topical Expert meeting

"System Integration of wind turbines"

Dublin, 9 / 10 November 2004

ECOFYS, Karsten Burges

ECOFYS

Overview

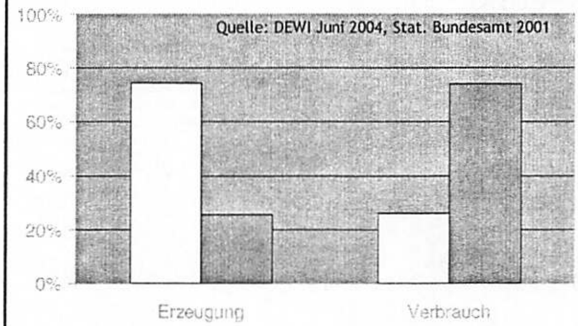
- Background and major challenges
- Control actions
- Discussion
- Conclusions and further steps

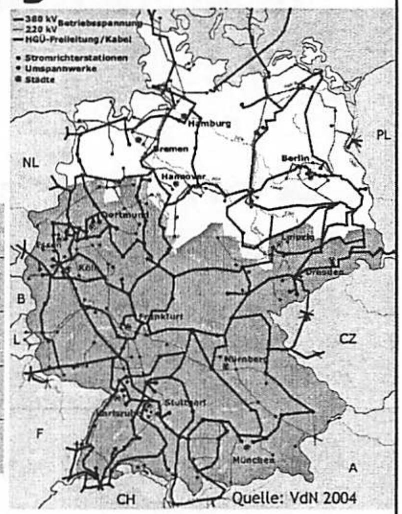
A SUSTAINABLE ENERGY SUPPLY FOR EVERYONE

ECOFYS

Background & challenge 1)

- Illustrating example D:
  - Installed wind capacity >15 GW
  - Regional differences





Controlling wind farms according to TSO requirements

ECOFYS

Background & challenge 2)

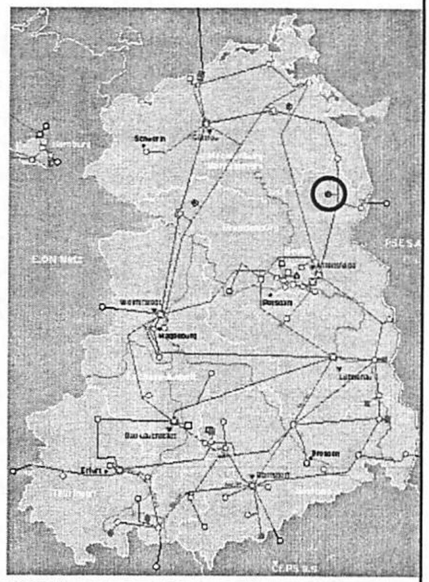
- TSO: system operation
  - Low load: high share in generation ➔ system stability and generation adequacy
  - Peak load: regional imbalances and limited transmission capacity to neighbouring TSO areas ➔ congestion management
  - Reserve (power and energy)
- TSO: network reinforcement and extension
- Wind farms: operational requirements become more similar to conventional power plants (Grid Codes)

A SUSTAINABLE ENERGY SUPPLY FOR EVERYONE

ECOFYS

Case studies: D [1)]

- Mixed wind farm (4 manufacturers)
- ca. 70 MW
- Directly connected to transmission system (220 kV)

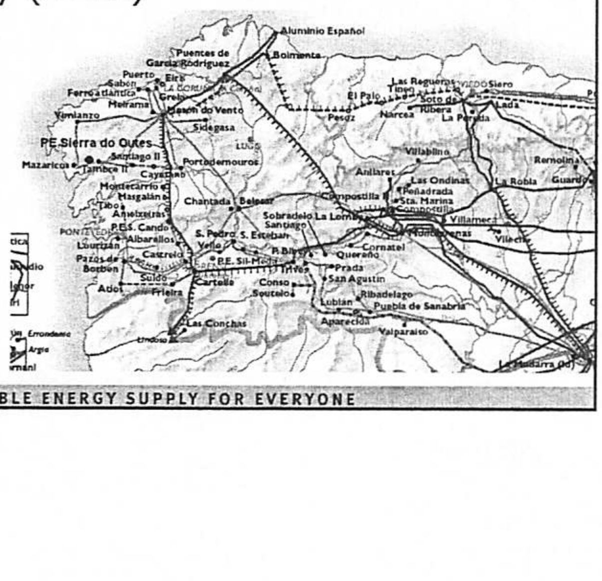


Controlling wind farms according to TSO requirements

ECOFYS

Case studies: ES [2)]

- Wind farm ca. 40 MW
- Single technology (DFIG)
- connected to 132 kV (distribution)



A SUSTAINABLE ENERGY SUPPLY FOR EVERYONE

Controlling wind farms according to TSO requirements

ECOFYS

Control actions

Action	Motivation	Implementation
A: active power curtailment	1. Reducing line loading / congestion 2. Increasing system stability	Curtailment 50% of actual MW capability
B: delivery of reactive power	Control voltage in case of low load	Fixed cosφ at all WEC's and PCC
C: anticipating curtailment	Enabling delivery of MW reserve (P)	50% curtailment

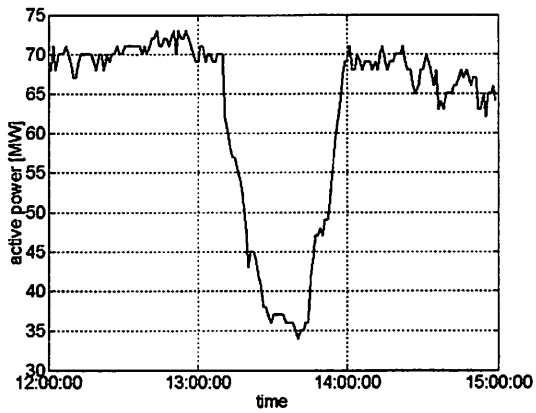
A SUSTAINABLE ENERGY SUPPLY FOR EVERYONE

Controlling wind farms according to TSO requirements

ECOFYS

A: Active power curtailment 1)

- Steady reduction: sequential activation of the individual WECs
- 70MW ➔ 35MW in 15 min, i.e. 3%/min



3 Sec. instantaneous values, PCC

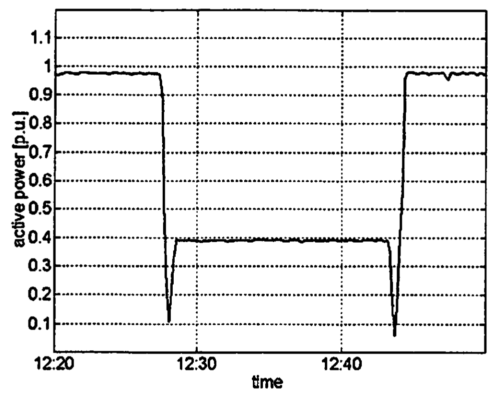
A SUSTAINABLE ENERGY SUPPLY FOR EVERYONE

Controlling wind farms according to TSO requirements

ECOFYS

A: Active power curtailment 2)

- Individual WEC: steep decrease / increase of active power > 50%/min
- Given suitable control mechanism (broadcasting) extreme dynamical control behaviour of the wind farm achievable



10 Sec. instantaneous values, WECs

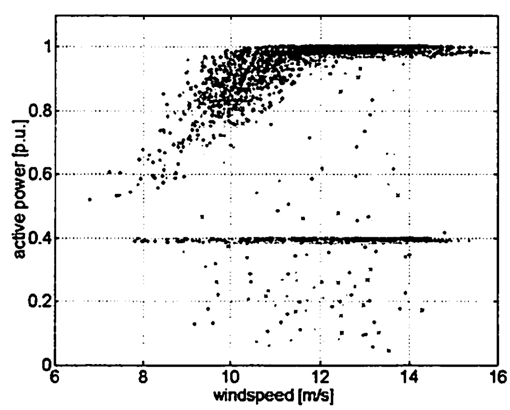
A SUSTAINABLE ENERGY SUPPLY FOR EVERYONE

Controlling wind farms according to TSO requirements

ECOFYS

A: Active power curtailment 3)

- P(v) characteristics of individual WEC's
- Power control highly accurate (steady state and dynamic behaviour)



10 Sec. instantaneous values, WECs

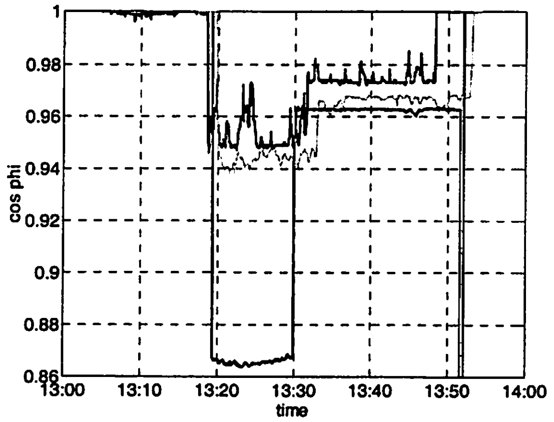
A SUSTAINABLE ENERGY SUPPLY FOR EVERYONE

Controlling wind farms according to TSO requirements

ECOFYS

B: Reactive power control 3)

- Mixed wind farm, individual WECs
- fixed cosφ, varying setpoint in steps
- Active power not affected
- Control via manufacturer
- fast response



1 & 10 sec. instantaneous values, WECs

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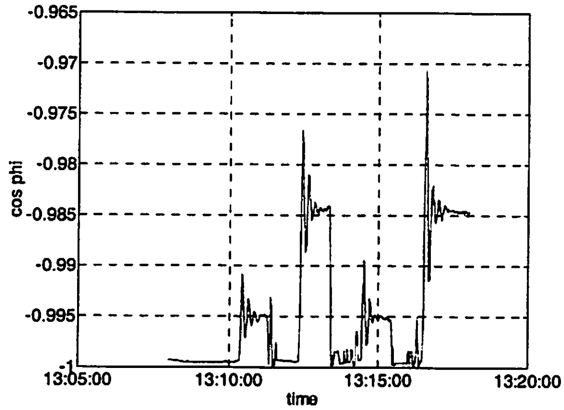
Controlling wind farms according to TSO requirements

ECOFYS

B: Reactive power control 1)

- Characteristics at PCC
  - blue / red: leading / lagging
- Fast response (damping to be optimised)
- Voltage control more complex



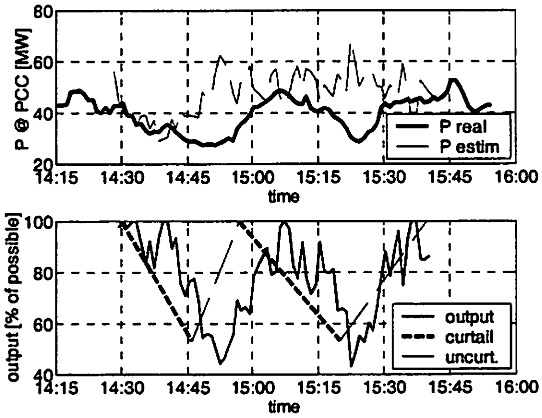
3 Sec. instantaneous values, PCC

A SUSTAINABLE ENERGY SUPPLY FOR EVERYONE

ECOFYS

C: Anticipating curtailment

- Accidental correlation of curtailment and reduction of wind speed
- Fixed curtailment ➔ reserve capacity in curtailed mode fluctuating
- Reference? compromise wind measurements from nacelles



1 min. averages

ECOFYS

Conclusions and further steps

- Control capabilities demonstrated. (pilot phase!)
- Fast response, even when based on telephone(!), and even when involving several manufacturers.
- Large scale application:
  - More than 90% of wind capacity at lower network levels - invisible for TSO!
  - More effective communication technologies (IEC 61400 - 25)!
- Legal framework: economic and legal matters to be discussed (definition and verification of operational conditions requiring control, yield losses, tariffs / compensation, warranty and liability, etc.)

Controlling wind farms according to TSO requirements

ECOFYS

Thank you !

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A SUSTAINABLE ENERGY SUPPLY FOR EVERYONE

System Integration of Wind Turbines in Ireland

Mark O'Malley

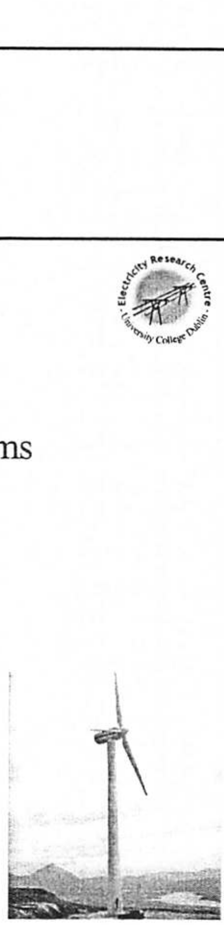
IEA TOPICAL EXPERT MEETING ON SYSTEM INTEGRATION OF WIND TURBINES

Dublin

9th November 2004

Wind in Ireland

- Irish electricity system
  - Two synchronised transmission systems Republic & Northern Ireland (3:1)
  - 500MW DC connection to Scotland
  - 6.2 GW peak, 2.2 GW trough
- Wind in Republic (Nov 2003)
  - 166 MW - connected
  - 600 MW – signed agreements/offers
  - 520 MW – applications
- Model of larger systems



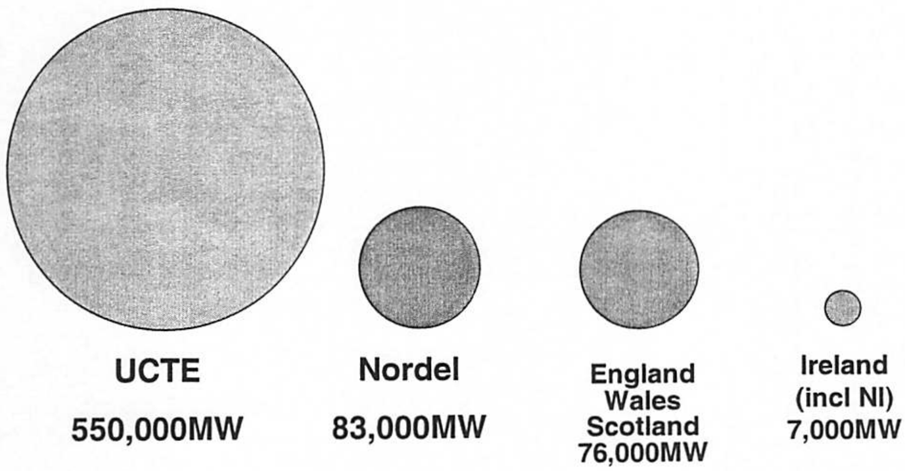
Wind in Ireland

- Dec 3rd 2003 Moratorium on Wind connections
- Transmission System Operator Concerns
  - Increase too rapid
  - Relatively small size (Island System)
- Technical issues
  - Grid code for wind, voltage control
  - Grid code derogations
  - Fault ride through
  - Validated wind turbine models – for dynamic studies
  - Operations, forecasting & ancillary services

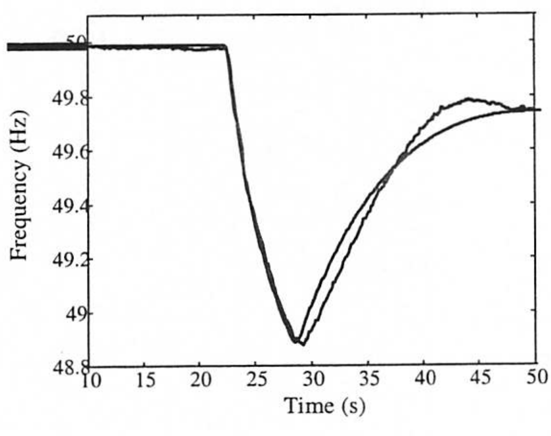
Wind in Ireland

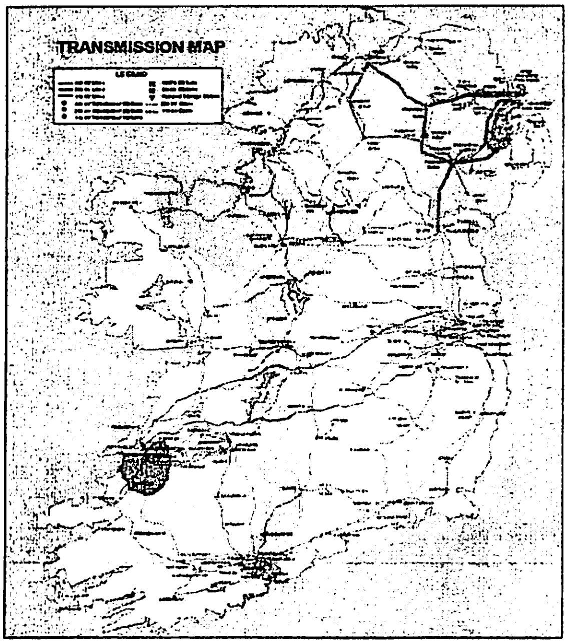
- Wind in Republic (July 04)
  - 240 MW - connected
  - 600 MW – signed agreements
  - 1600 MW – applications
- Applications & support mechanism are not synchronised
- Process is now hopelessly blocked
- Potential for stranding of assets
- Clustering approach being proposed

European Synchronous Power System
Total Generation Capacities



Frequency fall - Ireland





Fault

Voltage Profile

- Red < 15 %
- Yellow 15 – 50 %
- Green 50 – 80 %

Moratorium on wind

- Lifted October 2004
- New Grid Codes for wind
  - Fault Ride Through
- Wind Turbine Generator Models
  - Validation
- Non dispatchable nature
  - Constraining off
- Connection process is still blocked

ERC Wind Integration Projects

- Wind Power & Operation of Power Systems
- Wind power and frequency control
- Wind Turbine Generator Modelling
  - Data gathering
- Optimal Allocation of Embedded Generation
- Emissions and Wind Power

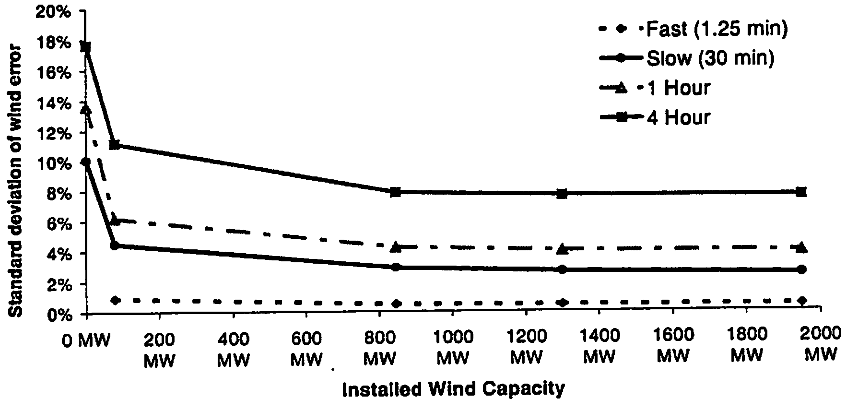
Operating Reserve Requirements as Wind Power Penetration Increases in the Irish Electricity System

http://www.sei.ie/uploads/documents/upload/publications/Ilex-Wind-Reser_rev2FSFinal.pdf

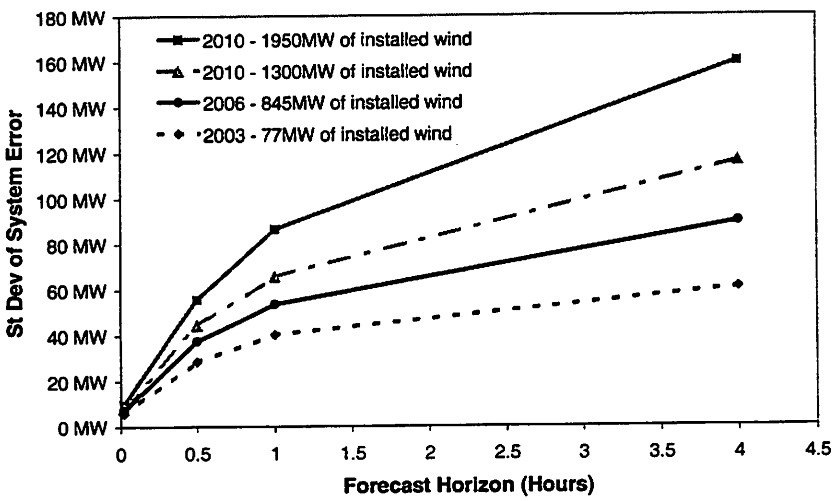
Doherty, R. and O'Malley, "New approach to quantify reserve demand in systems with significant installed wind capacity", *IEEE Transactions on Power Systems*", in press, 2004.

Wind forecast error

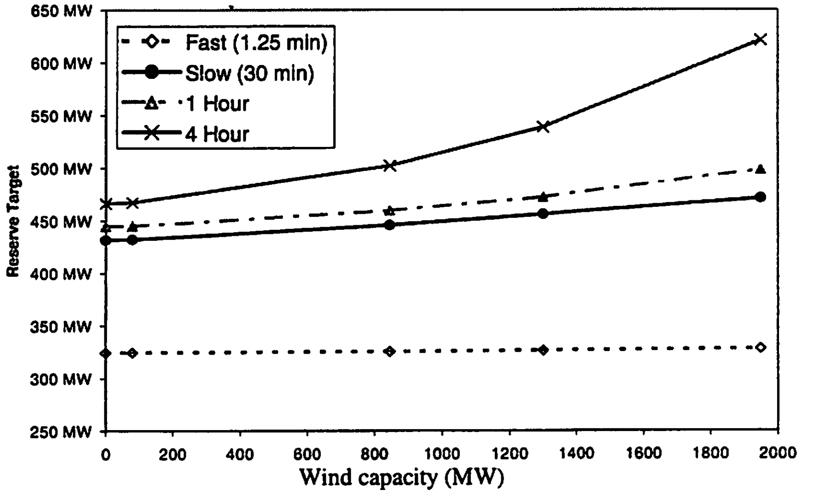
- As capacity increases, diversity reduces forecast error - diversification effectively maximised by 800MW



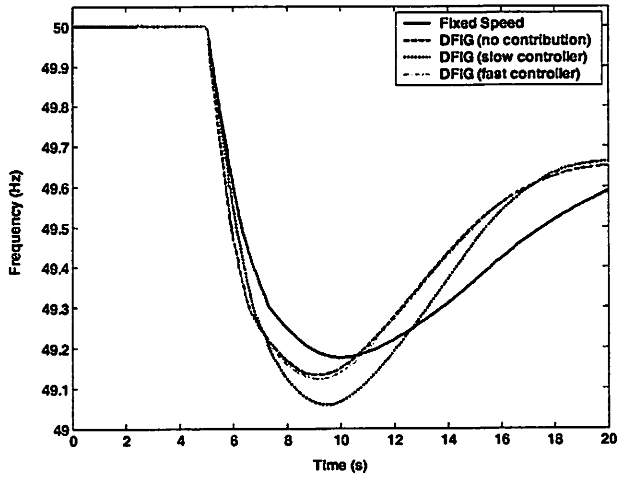
Impact of wind generation on system error



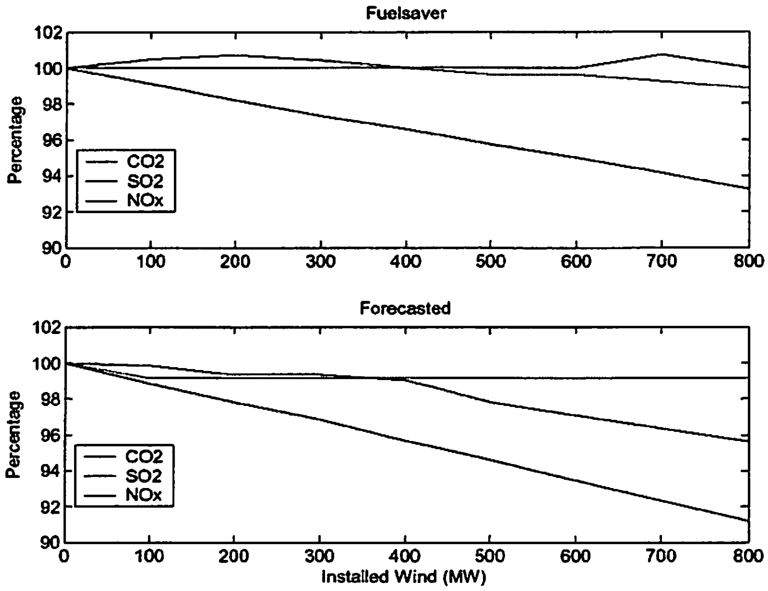
Operating reserve targets



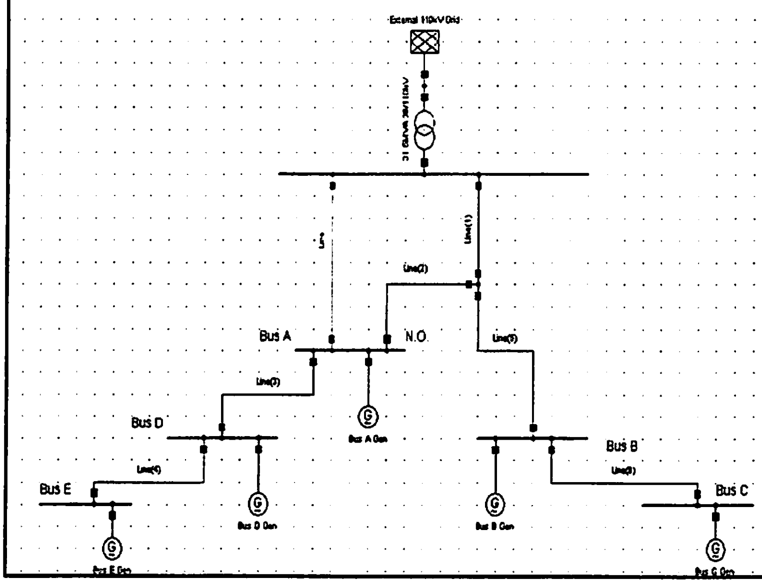
Dynamics: impact on system inertia

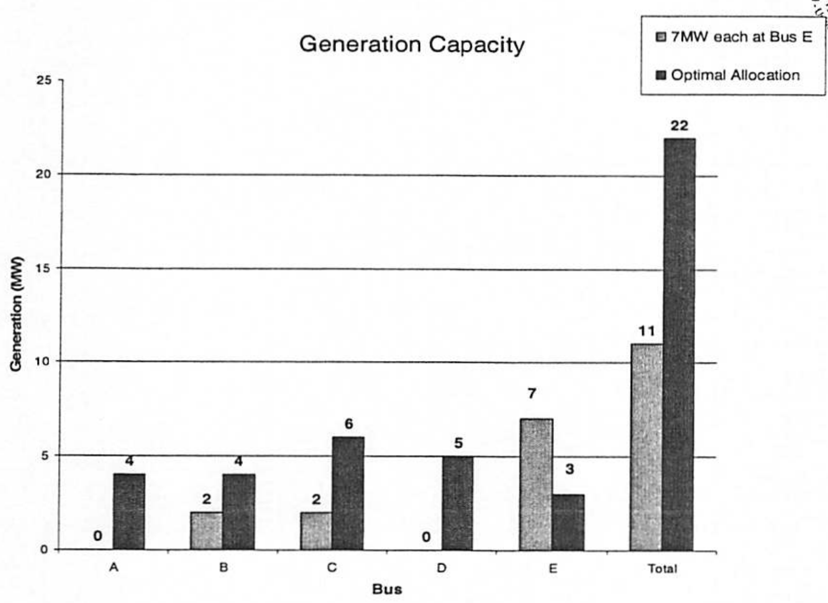


Emissions



Optimal grid development





Conclusions

Generation Mix

Dave O'Connor, IWEA

Topical Expert Meeting
System Integration of Wind Turbines

Dublin 9-10 November 2004

Peaking	Cheap to build
	Expensive to run
	Fast start capability
Mid-merit	Wide operational load range
	Reasonably good efficiency across load range
	Reasonably low emissions across load range
	Low start-stop costs – fuel and wear-and-tear
	Low wear-and-tear – large, fast load changes
Base load	Cheap to run
	Expensive to build
	High efficiency at full load
	Low emissions at full load

Evolution of Generation Mix

Hydro
Steam turbines
Reheat steam turbines
Pumped storage
Gas turbines
Combined cycles
Wind

1920 1930 1940 1950 1960 1970 1980 1990 2000 2010

With a significant amount of wind connected, what's needed when:

- A large generator trips? **Responsiveness!**
- Wind power drops dramatically? **Flexibility!**

Responsiveness and Flexibility

■ **Reheat Steam Turbines**	Reheater time constant
■ **Gas turbines**	Part-load operation Response to frequency dips
■ **Combined cycles**	Good efficiency at full load All else bad Already too many Ill-suited

Today's Generation Mix is Extremely Uncomplementary to Wind

- Grid code derogations
- Wind being penalised
- New Grid Code for Wind
- Report on cost of wind
- Proposals for constraint

Can anything be done to improve matters with:

- The existing generation mix?
- New plant additions?

Existing Generation Mix:

Unconventional Solutions to the Challenges of the 70s and 80s

- Open steam turbine valves three times faster
- Shut off bled steam line in a second for power boost
- Stop condensate flow for two minutes
- Open hydro valves eight times faster
- Operate hydro – synchronised – dewatered with compressed air

Unconventional Solutions to the Challenges of the 70s and 80s (continued)

- Go to peak firing temperature a hundred times faster
- Throttle steam flow *vs.* sliding pressure operation
- Avoid gas turbines drawing 150 MW for 6 seconds after tripping
- Convert 90% of trips to wind-down of load over 40 seconds
- Keep plant hot offload with insulation and revised procedures
- Halve startup times with intelligent supervisory controls

New Plant Additions: New Generation of Aeroderivative Gas Turbines

- 100 MW
- Full-load efficiency of 45% – better than some combined cycles on the system
- Excellent part-load efficiency profile
- Low emissions
- Very fast starts and good load following capability
- Negligible wear-and-tear from start-stop cycles
- No loss of output during frequency dips
- Half the capital cost of combined cycles if installed on retired power station sites.

What Needs to be Done

- Signals to the Market
  - ➡ all new generating plant is of the optimum type
- New Grid Code for *Thermal* Generators
  - ➡ provide responsiveness and flexibility to the optimum degree
- New Market Mechanisms
  - ➡ *all* generators provide optimum responsiveness and flexibility
  - ➡ the *market* to determine constraint.

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Control of DFIG Wind Turbines for Power Network Operation Support

Olimpo Anaya-Lara and Nick Jenkins

IEA Annex XI Topical Expert Meeting
November 9-10, Dublin, Ireland

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Topics

- UK Government objectives for 2010
- Research support
- Current projects
- DFIG control design
- Summary

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UK |Government 2010 Objectives

- 10% of UK electricity supply provided by renewable energy sources.
- High contribution expected from wind energy.
- Future wind farms based on DFIG configurations.
- Grid Code compliance of DFIG wind turbines.

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Research Support

- DTI Centre for Distributed Generation and Sustainable Electrical Energy.
- EPSRC Supergen Initiative for Future Network Technologies.

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Industrial Collaborators

- National Grid (Transco) Company
- Scottish and Southern Energy
- Scottish Power
- AREVA
- ABB

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Current Projects

- Protection methods for active distribution networks with high penetration of distributed generation.
- UK Generic Distribution System (UKGDS) model in order to provide a common base for the simulation and analysis of the impact of distributed generation on the operation, performance, economics and development of the UK distribution networks.
- Control of doubly fed induction generators for wind farm operation.

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Control of DFIGs for wind farm operation

Development of control schemes that enable a DFIG to contribute to network operation and to satisfy new Grid Code requirements:

- Voltage control and recovery following network faults.
- Frequency regulation following loss of network generation.
- Positive contribution to network damping.
- Fault ride through capability.
- Compatibility with conventional generation dynamic characteristics.

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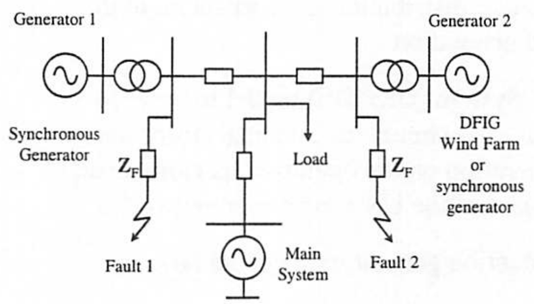
Generic network model



- Platform used for DFIG control scheme design and performance prediction.
- Main system may be represented by infinite bus or equivalent synchronous generator models.
- Suitable for transient and small signal stability studies.

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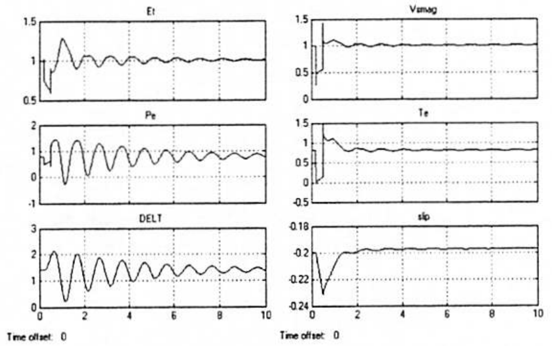
Main system model: infinite bus

Generator 1 responses

Synchronous generator



Generator 2 responses

DFIG

Fault 2 applied near DFIG wind farm at t = 0.2s

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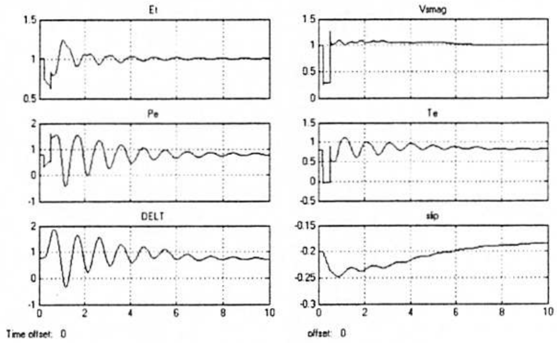
Main system model: equivalent synchronous generator

Generator 1 responses

Synchronous generator



Generator 2 responses

DFIG

Fault 2 applied near DFIG wind farm at t = 0.2s

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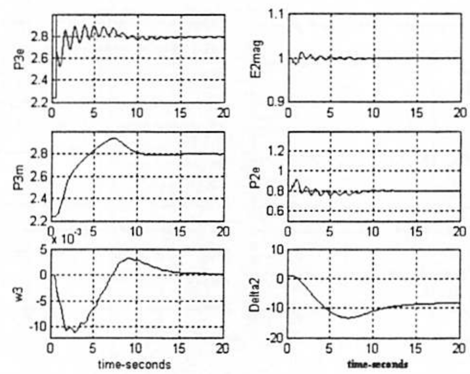
Frequency support

Main system responses

Synchronous generator



Generator 2 responses

Synchronous generator

Loss of generation at t = 0.2s

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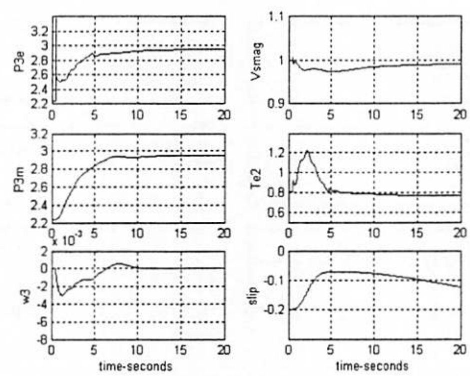
Frequency support

Main system responses

Synchronous generator



Generator 2 responses

DFIG

Loss of generation at t = 0.2s

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November 9-10, Dublin, Ireland

Summary

Long-term dynamics of power systems

IEA Topical Expert Meeting #44
9-10.11.2004 Dublin

Sanna Uski & Bettina Lemström

Types of power system simulations

- Steady state
  - power flow
  - voltage stability analysis (PV-, VQ-curves etc.)
  - fault current calculation
- **Long term dynamics**
- Stability
  - impact of faults, disturbances on the power system
  - large voltage and frequency excursions
  - also unstable situations
- Electromagnetic transients
  - faults, switching-events, protection
  - local studies

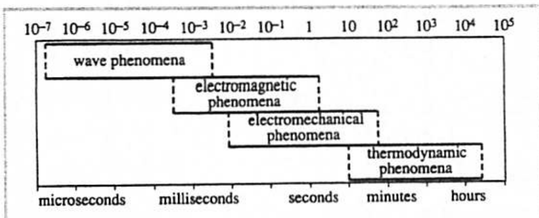
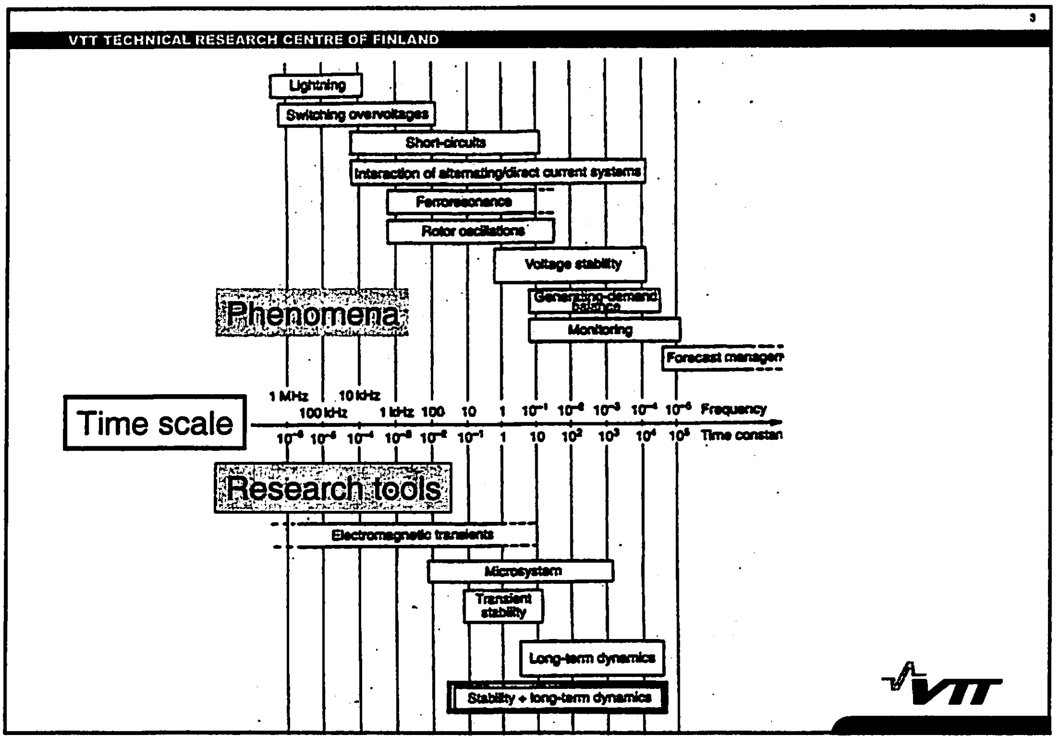


Figure 1.1 Time frame of the basic power system dynamic phenomena



Long term dynamics

- real behaviour of the power system during a period of time ranging from ten seconds to hours
- includes
  - electromechanical rotor transients
  - turbine and boiler dynamics
  - protection
  - automation
  - centralised controller actions
  - load change
  - power plant and system operator actions

Tool: PSS/E & Extended term dynamics -module

- uses mainly same input as ordinary PSS/E dynamic modelling
- possible to include
  - transformer tap changers
  - boiler effects
  - action of excitation limiters
  - switching of capacitors and reactors
  - restoration of loads etc.
- suitable tool for studying
  - secondary control
  - power plant dispatch
  - voltage and frequency variations
  - transmission capacity and bottlenecks

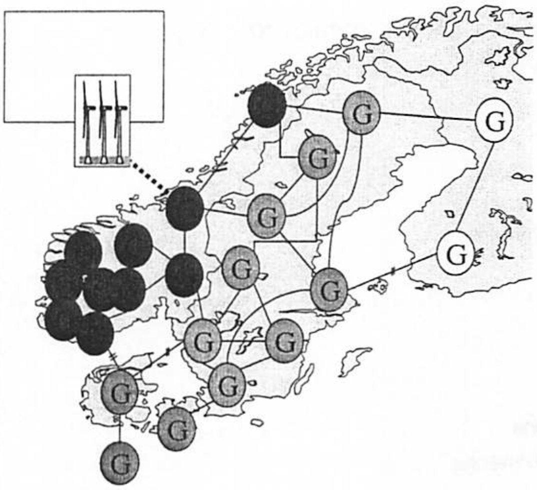
VTT TECHNICAL RESEARCH CENTRE OF FINLAND

Tool: PSS/E & Extended term dynamics -module

- time step is user-defined and can vary during the simulation
- three different modes depending on time step in order to include high-frequency characteristics in different degree :
  - for small time step (~ half cycle)
  - for medium time step (~ three to six cycles)
  - for large time step (~ 0,15 - 0,2 s)
- additional models:
  - Online Tap Changer
  - Online Phase Shifter
  - dc Line Tap Changer
  - Maximum Exitation Limiters

7

Simulation example



- Sintef 23-generator model
  - loads at 25 nodes
  - base case consumption 49.5 GW
  - loads modelled as
    - P: 40 % constant Z, 60 % constant I
    - Q: 100% constant Z
- Additional wind power
  - 5 GW in mid-Norway
  - modelled as negative P-load
    - 100 % constant power

VTT

8

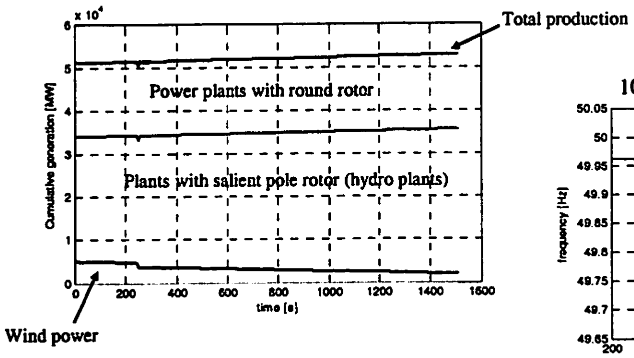
Simulation example

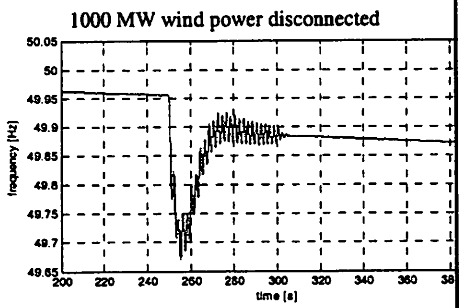
Basic assumptions for the simulated case:

- Load increases linearly
  - Actual load increase based on hour to hour consumption in Nordel-area one autumn morning (→ total increase 4952 MW = 10 %)
  - Country-wise load increase is shared among loads in that country proportional to the initial values of the loads
  - "Linear" load increase is modelled stepwise (5 s steps)
- Linear wind power decrease rate of 50% in 30 min is used
- Additionally a sudden disconnection of 1000 MW wind power at time 250 s

VTT

Simulation example





- wind power is replaced by hydro power
- hydro power reacts fast to sudden changes in power balance
- conventional plants do not change production much or fast

VTT

System Integration of Wind Turbines

Dynamic Modelling of Wind Turbine Generators in Ireland

Global Dynamic Studies

Jane McArdle
ESBNG, Power System Planning

9th November 2004

ESB NATIONAL GRID

Presentation Overview

- Wind Farm Development in Ireland
- Wind Turbine Generator Types in Ireland
- Status of PSS/E Wind Turbine Generator Models
- Global Dynamic Studies
  - Objectives
  - Scope
  - Phases of the Study
- Modelling Summary

ESB NATIONAL GRID

Wind Farm Development in Ireland

Status	MW	Cumulative Total
Connected	226	226
Contracted	604	830
~Applications & Live Offers (4th November)	2,000+	2,830+

ESB NATIONAL GRID

To ensure the stability of the system is not in danger

We need to dynamically model the system with all this wind power

……For this we need models

Wind farm developers are not installing the same wind turbines generator types at all their sites

….but many different ones

Each type requiring a model

ESB NATIONAL GRID

The following table gives a breakdown of the wind turbine generators both connected to the Irish System and listed in applications to connect

It also gives details of the Status of the dynamic models available for these units

	Manufacturer	Type	Output	Stage 1 Model available	Suitability for System Studies	Remarks

ESB NATIONAL GRID

	Manufacturer	Type	Output	Stage 1 Model available	Suitability for System Studies	Remarks
1	Bonus		2.3MW	✓	X	Single Mass representation
2	Bonus		1.3MW	✓	X	Single Mass representation

NATIONAL GRID

	Manufacturer	Type	Output	Stage 1 Model available	Suitability for System Studies	Remarks
1	Bonus		2.3MW	✓	X	Single Mass representation
2	Bonus		1.3MW	✓	X	Single Mass representation
3	DeWind	D6	1.25 MW	✓	✓	
4	DeWind	D8	2 MW	✓	✓	

NATIONAL GRID

	Manufacturer	Type	Output	Stage 1 Model available	Suitability for System Studies	Remarks
1	Bonus		2.3MW	✓	X	Single Mass representation
2	Bonus		1.3MW	✓	X	Single Mass representation
3	DeWind	D6	1.25 MW	✓	✓	
4	DeWind	D8	2 MW	✓	✓	
5	Enercon	E40	500kW	✓	X	Initialisation and Tstep
6	Enercon	E66	1.8MW	✓	X	Initialisation and Tstep
7	Enercon	E66	2 MW	✓	X	Initialisation and Tstep
8	Enercon	E70	2 MW	✓	X	Initialisation and Tstep

ESB NATIONAL GRID

	Manufacturer	Type	Output	Stage 1 Model available	Suitability for System Studies	Remarks
1	Bonus		2.3MW	✓	X	Single Mass representation
2	Bonus		1.3MW	✓	X	Single Mass representation
3	DeWind	D6	1.25 MW	✓	✓	
4	DeWind	D8	2 MW	✓	✓	
5	Enercon	E40	500kW	✓	X	Initialisation and Tstep
6	Enercon	E66	1.8MW	✓	X	Initialisation and Tstep
7	Enercon	E66	2 MW	✓	X	Initialisation and Tstep
8	Enercon	E70	2 MW	✓	X	Initialisation and Tstep
9	Gamesa	G52	850kW	✓	X	Tstep
10	Gamesa	G8X	2 MW	✓	X	Tstep

ESB NATIONAL GRID

	Manufacturer	Type	Output	Stage 1 Model available	Suitability for System Studies	Remarks
1	Bonus		2.3MW	✓	X	Single Mass representation
2	Bonus		1.3MW	✓	X	Single Mass representation
3	DeWind	D6	1.25 MW	✓	✓	
4	DeWind	D8	2 MW	✓	✓	
5	Enercon	E40	500kW	✓	X	Initialisation and Tstep
6	Enercon	E66	1.8MW	✓	X	Initialisation and Tstep
7	Enercon	E66	2 MW	✓	X	Initialisation and Tstep
8	Enercon	E70	2 MW	✓	X	Initialisation and Tstep
9	Gamesa	G52	850kW	✓	X	Tstep
10	Gamesa	G8X	2 MW	✓	X	Tstep
11	GE	TW1.5s	1.5MW	✓	✓	
12	GE	3.6s	3.6MW	✓	X	CP data

ESB NATIONAL GRID

	Manufacturer	Type	Output	Stage 1 Model available	Suitability for System Studies	Remarks
1	Bonus		2.3MW	✓	X	Single Mass representation
2	Bonus		1.3MW	✓	X	Single Mass representation
3	DeWind	D6	1.25 MW	✓	✓	
4	DeWind	D8	2 MW	✓	✓	
5	Enercon	E40	500kW	✓	X	Initialisation and Tstep
6	Enercon	E66	1.8MW	✓	X	Initialisation and Tstep
7	Enercon	E66	2 MW	✓	X	Initialisation and Tstep
8	Enercon	E70	2 MW	✓	X	Initialisation and Tstep
9	Gamesa	G52	850kW	✓	X	Tstep
10	Gamesa	G8X	2 MW	✓	X	Tstep
11	GE	TW1.5s	1.5MW	✓	✓	
12	GE	3.6s	3.6MW	✓	X	CP data
13	NEG micon		600kW	X		ESBNG to Model
14	NEG micon		300kW	X		ESBNG to Model
15	NEG micon		450kW	X		ESBNG to Model
16	NEG micon	NM72	1.65 MW	✓	✓	NM72 or NM82
17	NEG micon	NM82	1.65 MW	✓	✓	

ESB NATIONAL GRID

	Manufacturer	Type	Output	Stage 1 Model available	Suitability for System Studies	Remarks
1	Bonus		2.3MW	✓	X	Single Mass representation
2	Bonus		1.3MW	✓	X	Single Mass representation
3	DeWind	D6	1.25 MW	✓	✓	
4	DeWind	D8	2 MW	✓	✓	
5	Enercon	E40	500kW	✓	X	Initialisation and Tstep
6	Enercon	E66	1.8MW	✓	X	Initialisation and Tstep
7	Enercon	E66	2 MW	✓	X	Initialisation and Tstep
8	Enercon	E70	2 MW	✓	X	Initialisation and Tstep
9	Gamesa	G52	850kW	✓	X	Tstep
10	Gamesa	G8X	2 MW	✓	X	Tstep
11	GE	TW1.5s	1.5MW	✓	✓	
12	GE	3.6s	3.6MW	✓	X	CP data
13	NEG micon		600kW	X		ESBNG to Model
14	NEG micon		300kW	X		ESBNG to Model
15	NEG micon		450kW	X		ESBNG to Model
16	NEG micon	NM72	1.65 MW	✓	✓	NM72 or NM82
17	NEG micon	NM82	1.65 MW	✓	✓	
18	Nordex	N80	2.5MW	✓	X	Tstep
19	Nordex	N60	1.3MW	X		

ESB NATIONAL GRID

	Manufacturer	Type	Output	Stage 1 Model available	Suitability for System Studies	Remarks
20	Vestas	V27	225kW	X		ESBNG to Model
21	Vestas	V39	600kW	X		ESBNG to Model
22	Vestas	V42	500/600kW	X		ESBNG to Model
23	Vestas	V47	660kW	✓	✓	
24	Vestas	V52	850kW	✓	X	Issues with FRT in model
25	Vestas	V66	1.75MW	✓	✓	
26	Vestas	V80	2 MW	✓	X	Issue with the damping of this model
27	Vestas	V90	3 MW	✓	✓	
	Unspecified			-	-	
	Total					

ESB NATIONAL GRID

	Manufacturer	Type	Output	Stage 1 Model available	Suitability for System Studies	Remarks
1	Bonus		2.3MW	✓	X	Single Mass representation
2	Bonus		1.3MW	✓	X	Single Mass representation
3	DeWind	D6	1.25 MW	✓	✓	
4	DeWind	D8	2 MW	✓	✓	
5	Enercon	E40	500kW	✓	X	Initialisation and Tstep
6	Enercon	E66	1.8MW	✓	X	Initialisation and Tstep
7	Enercon	E66	2 MW	✓	X	Initialisation and Tstep
8	Enercon	E70	2 MW	✓	X	Initialisation and Tstep
9	Gamesa	G52	850kW	✓	X	Tstep
10	Gamesa	G8X	2 MW	✓	X	Tstep
11	GE	TW1.5s	1.5MW	✓	✓	
12	GE	3.6s	3.6MW	✓	X	CP data
13	NEG micon		600kW	X		ESBNG to Model
14	NEG micon		300kW	X		ESBNG to Model
15	NEG micon		450kW	X		ESBNG to Model
16	NEG micon	NM72	1.65 MW	✓	✓	NM72 or NM82
17	NEG micon	NM82	1.65 MW	✓	✓	
18	Nordex	N80	2.5MW	✓	X	Tstep
19	Nordex	N60	1.3MW	X		
20	Vestas	V27	225kW	X		ESBNG to Model
21	Vestas	V39	600kW	X		ESBNG to Model
22	Vestas	V42	500/600kW	X		ESBNG to Model
23	Vestas	V47	660kW	✓	✓	
24	Vestas	V52	850kW	✓	X	Issues with FRT in model
25	Vestas	V66	1.75MW	✓	✓	
26	Vestas	V80	2 MW	✓	X	Issue with the damping of this model
27	Vestas	V90	3 MW	✓	✓	
	Unspecified			-	-	

…So what are we going to be doing with all these models….

ESB NATIONAL GRID

Global Dynamic Studies

The overall objective of this study is to assess the dynamic impact of high levels of wind generation on the Irish power system, in particular the impact on ***Transient*** *and* ***Voltage*** *stability.*

Objectives

Through this investigation, we would like to:

- Identify any limitations due to stability issues on the amount of wind generation that could be installed.
- Identify any measures necessary to ensure system stability.
- Investigate the stability performance of different wind turbine generator technologies.
- Investigate the impact on the results of different approaches to modelling wind turbine generators.

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Objectives

Following on, these studies will enable us to adopt standardised approaches to modelling wind generation.

Through:

- Simplification of models – e.g. algebraic modelling, longer time constants
- Aggregation techniques - Assessing the extent to which wind farms may be aggregated
- Procedures for simulations - Identifying appropriate techniques for setting up and running simulations.

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Scope

Four Phases, representing four different wind scenarios:

- **Phase 1** : all existing wind generation.
- **Phase 2** : all existing wind generation, together will all existing connection agreements.
- **Phase 3** : 1,000 MW, corresponding to the achievement of the RES-E Directive target for Ireland of 13.2% of electricity from renewables in 2010.
- **Phase 4** : will consider a future high wind penetration situation, based on the present wind applications.

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Modelling Summary

- Potentially there are 27 different types of wind turbine generators coming on to the Irish system…
- We have 8 models suitable for full system studies
- We have 12 models that are usable and getting there– but some are far from ideal.
- The remaining 7 are a very small proportion of the total wind penetration- however we have developed our own models for these machines.
- Validation of all these models is also required.

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Electrical Power and Market Operation with High Wind Power Penetration

Ola Carlson
Electric Power Engineering
Chalmers University of Technology

Input from a TSO

➢TSO- missing a proven dynamic model for wind turbines, farms

➢A forum for exchanging knowledge and experience on wind farm modelling for power system studies.

➢Increased knowledge in wind power generation, techniques, system impact consequences, modelling etc.

➢A complete PSS/E-model of wind farms including:

❖Wind turbine

❖Generator and converter

❖Control and Safety system

❖wind gusts and ramps

Input from a TSO

- TSO prefer one single model for wind farms (>10 MW) containing all parameters. It should be possible to choose type of wind power plant when you set up the model i.e. constant/variable speed, pitch/stall control, ac-type, dc/dc-converters...
- The model should be delivered in PSS/E data format, ready to use.
- The model should be sufficient for studies on:
- power system transient and long term stability
- power system operation
- The model should work with standard time step in PSS/E which is 0.01 seconds.

➢ Verification of the model by some tests either in laboratory or reality tests.

Measurements and simulation of Alsvik 180 kW wind turbine

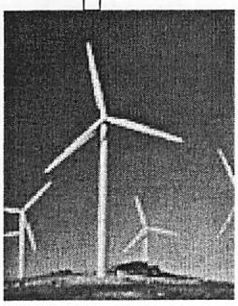
Simulation done by
Pablo Ledesma, PSS/E
Marcia Martins, DigSilent
Abram Perdana, Matlab

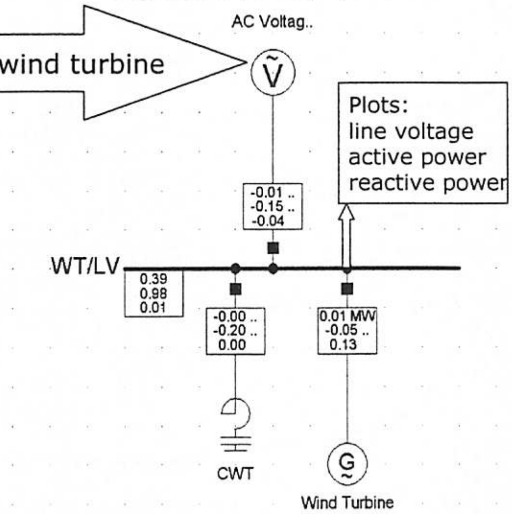
Measurements, Torbjörn Thiringer, Tomas Petru

Field measurements, simulations and validation

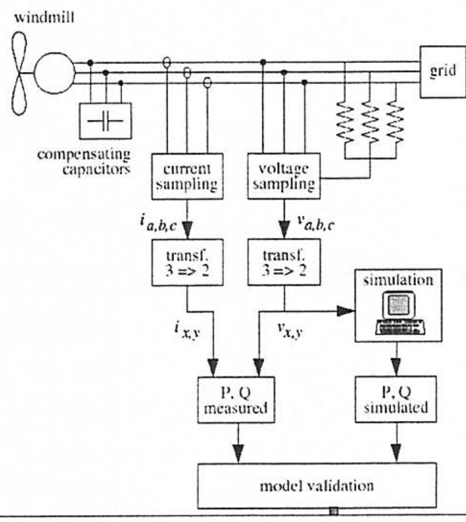
DigSilent , PSS/E, Matlab

Measurement file from Alsvik wind turbine

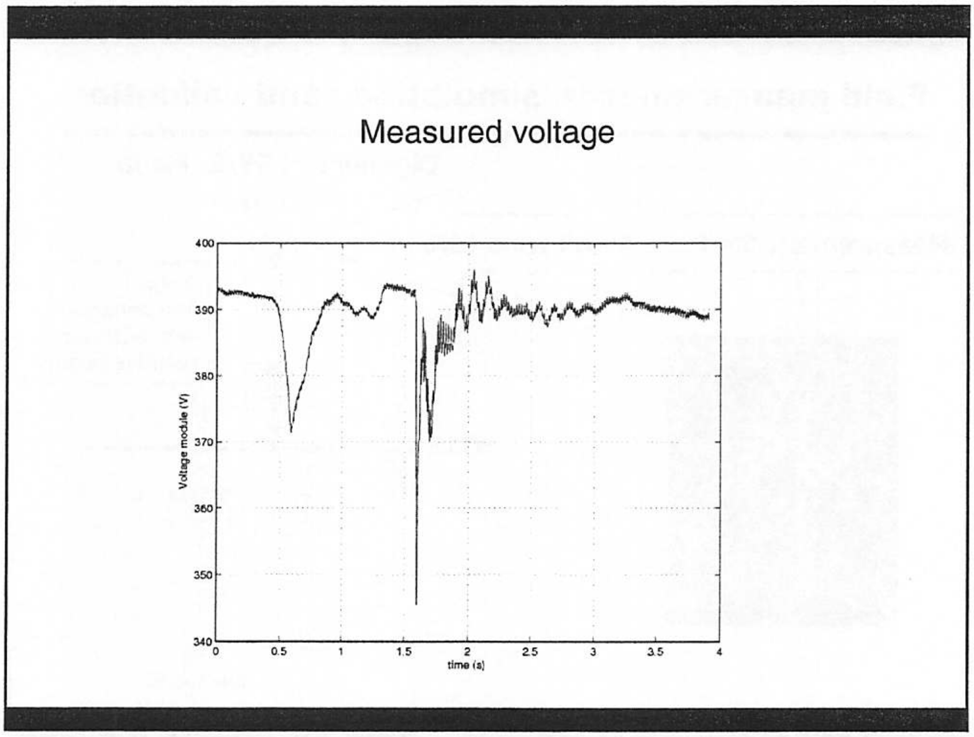


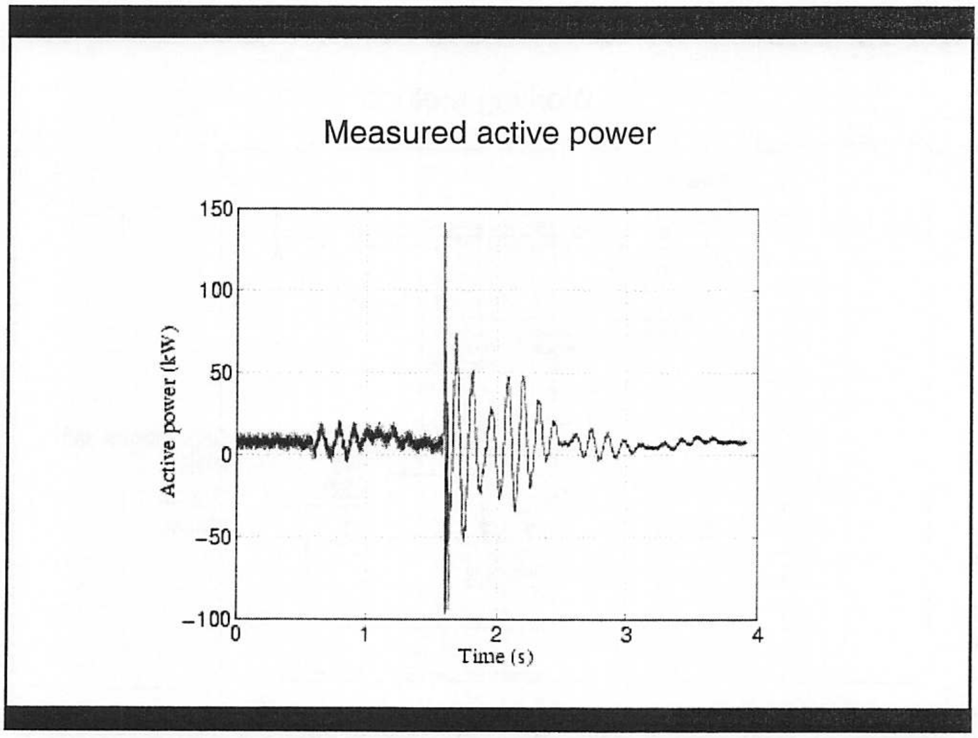


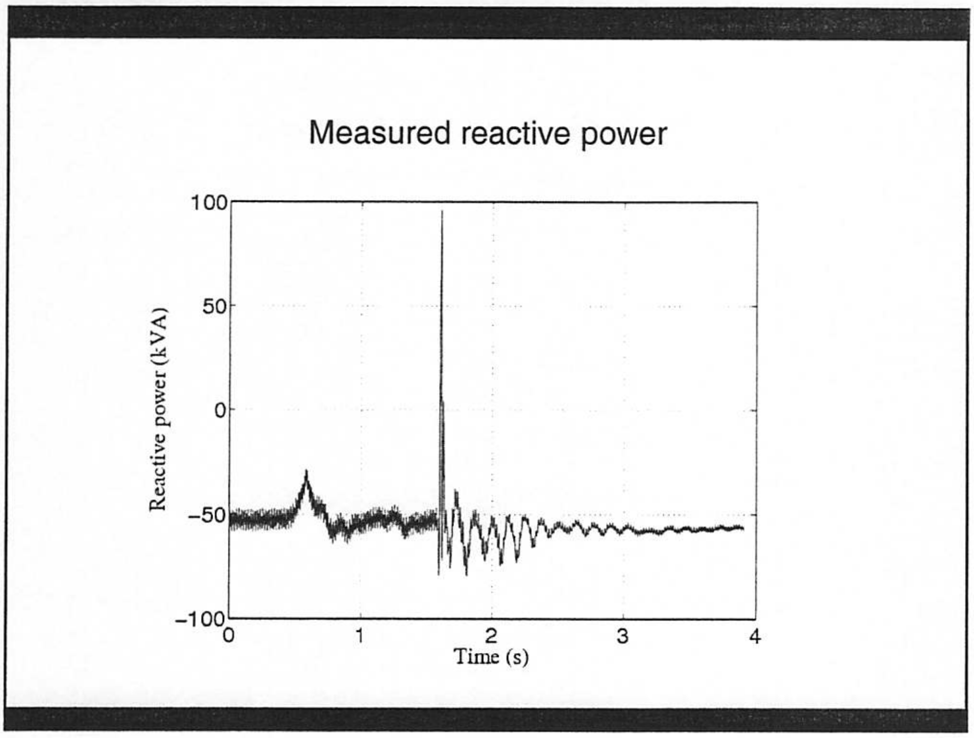
Working method

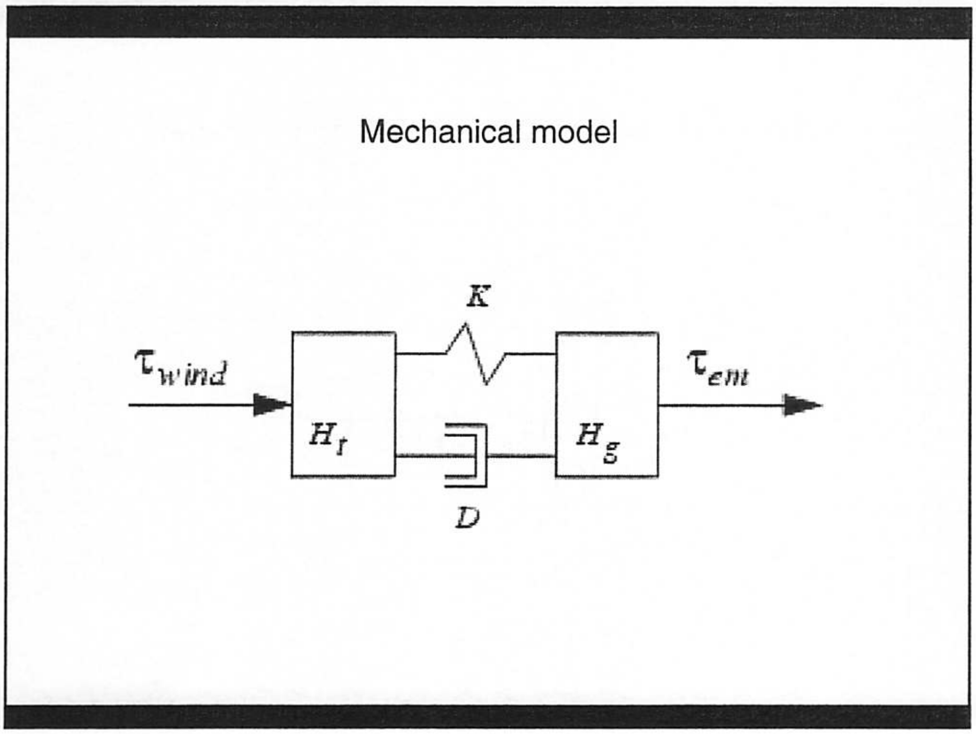


Simulations with
PSS/E
DigSilent
Matlab

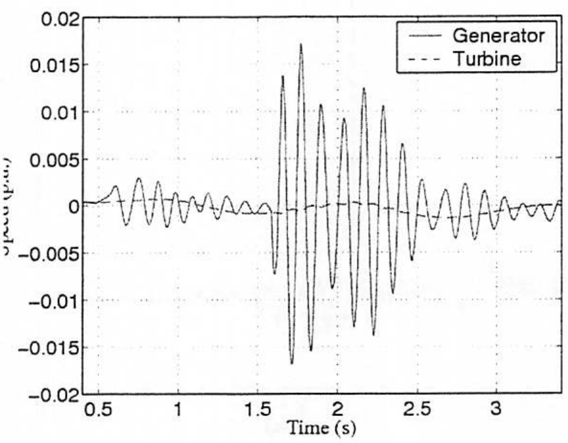

Measured voltage
Voltage module (V)
time (s)
400
390
380
370
360
350
340
0
0.5
1
1.5
2
2.5
3
3.5
4


Measured active power
Active power (kW)
Time (s)
150
100
50
0
−50
−100
0
1
2
3
4

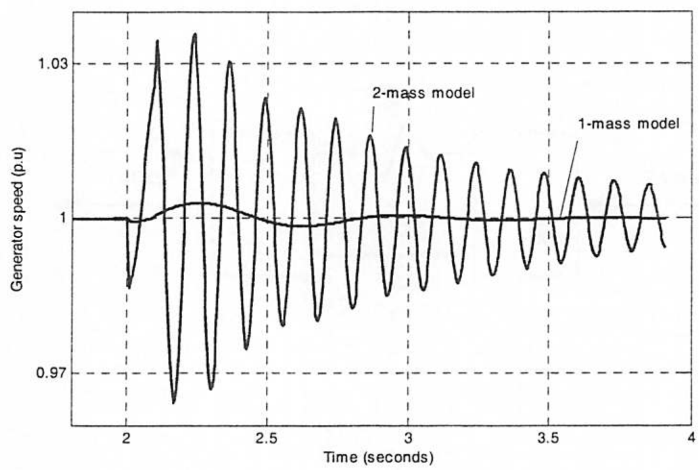

Measured reactive power
Reactive power (kVA)
Time (s)
100
50
0
-50
-100
0
1
2
3
4


Mechanical model
K
D
τ_{wind}
τ_{em}
H_t
H_g

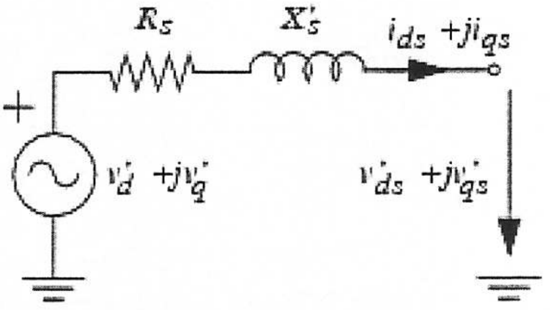
Generator and turbine speed



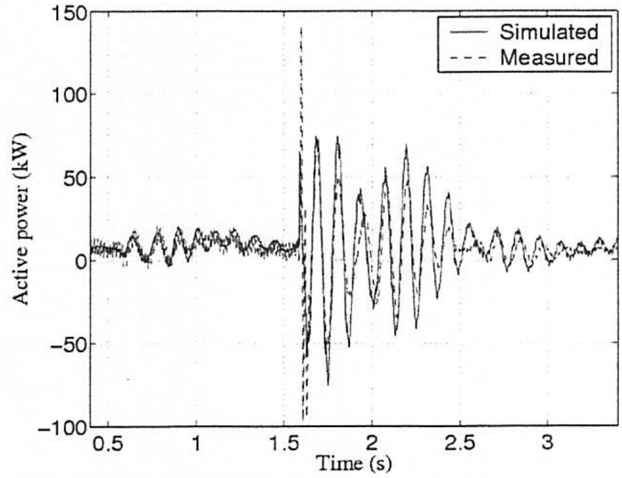
One – two mass model (not the same voltage)



Induction generator model neglecting stator transient

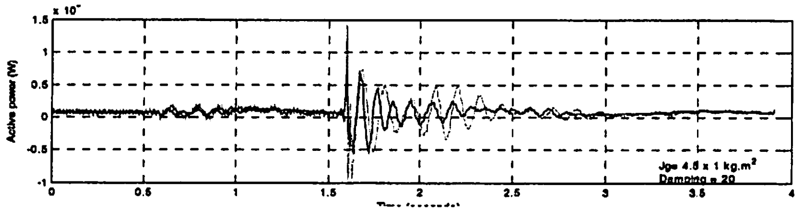


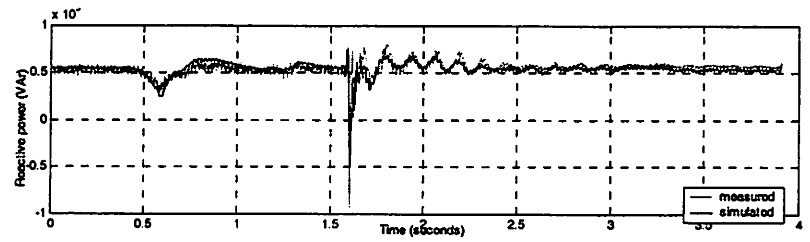
Sim/Meas active power neglecting stator transients and Jgen*2



Field measurements and simulations

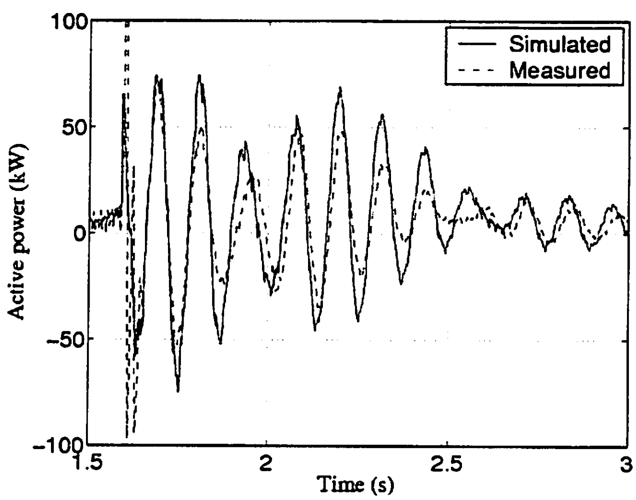
Matlab simulation with measured line voltage as input



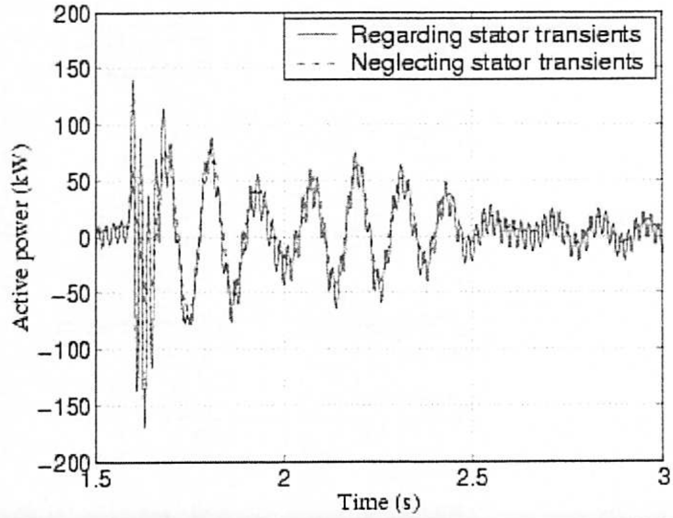


Detail

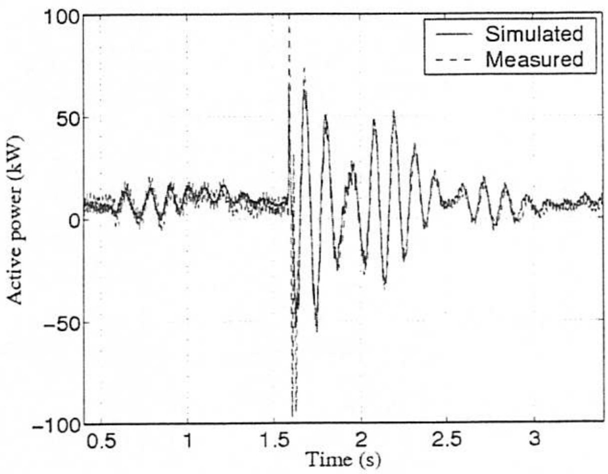
Sim/Meas active power neglecting stator transients



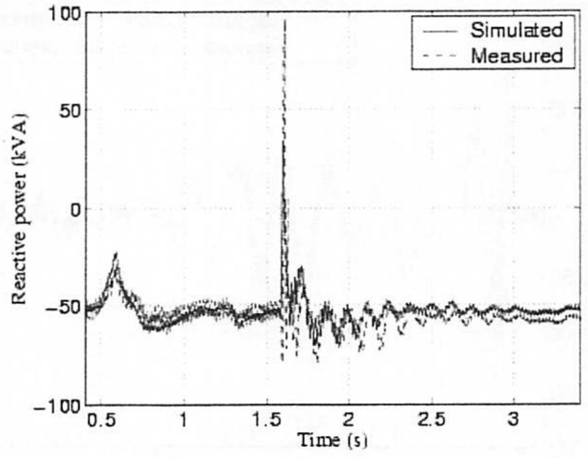
Regarding/Neglecting stator transients
(5/3-order model)



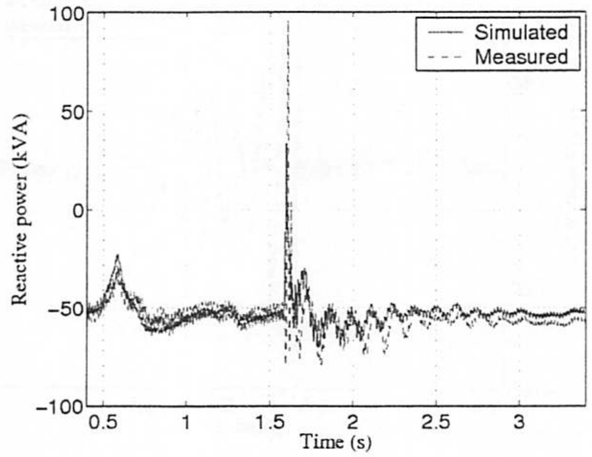
Sim/Meas active power neglecting stator transients but including mechanical damping (large imporvement)



Simu/Meas reactive power neglecting stator transients



Sim/Meas reactive power neglecting stator transients but including mechanical damping (no different)

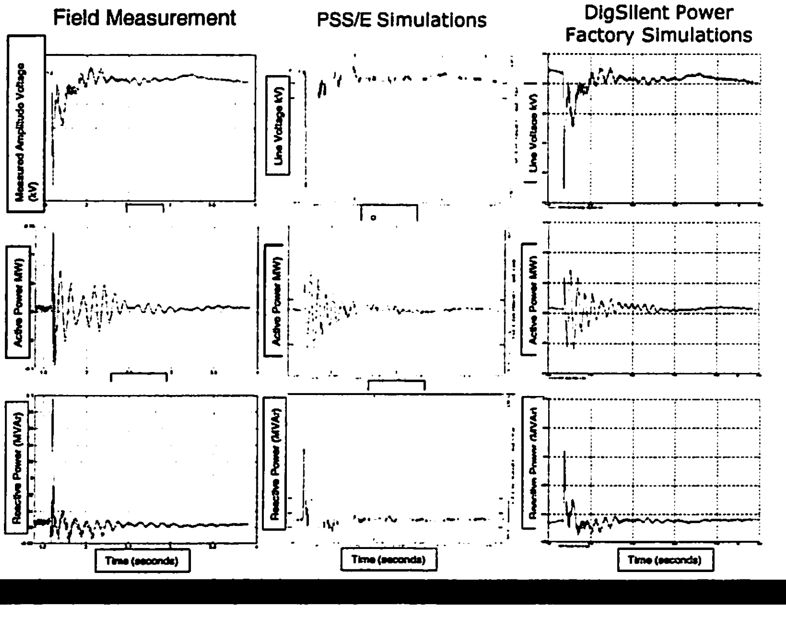


Field measurements and simulations

Conclusions:

- Results show good agreement: similar oscillations, similar amplitude, slightly difference in frequency (measurements shows higher oscillations than the simulations if no damping).
- The differences in the frequency oscillations between the measurements and simulations are due to the inertia (J) of the generator and stiffness (K) of the mechanical shaft.
- The very fast transient at the first moment depends on the time constant. The results are focused in the electromechanical transients not in the electromagnetic transients.
- Model must have 2 masses represented. Using just one lumped model affects the high speed oscillation.

Field measurements and simulations



There is a need for
validated models of
all types of wind turbines
and
aggregated models for
wind farms

Integrating Wind into the Transmission Grid

Michael C Brower, PhD
AWS Truewind LLC
Albany, New York
mbrower@awstruewind.com

AWS Truewind

About AWS Truewind

- Providing integrated consulting services to the wind industry
- Responsible for the Irish Wind Atlas (with ESBI, initiated by SEI)
- Forecasting for 2000+ MW of wind plant in US and Europe
- Conducted wind integration studies in US

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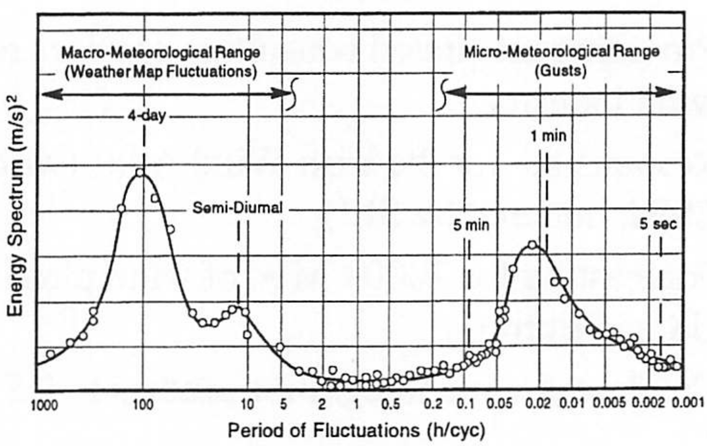
Time Scales – Electric Power

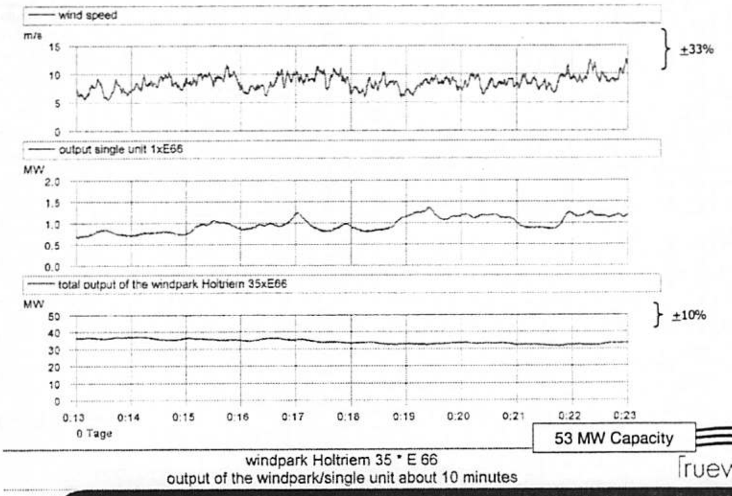
- Regulation: seconds to minutes
- Load following: minutes to hours
- Unit commitment: hours to days
- Reliability: months to years

Time Scales – Wind



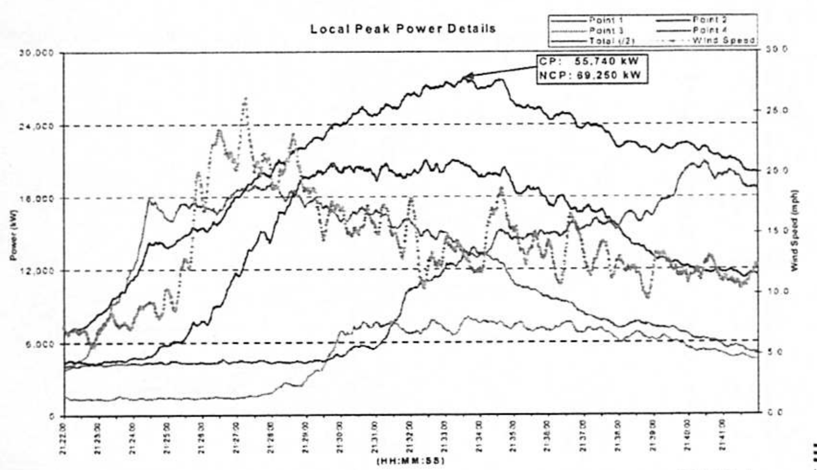
Wind and Wind Plant Variability

Not the Same



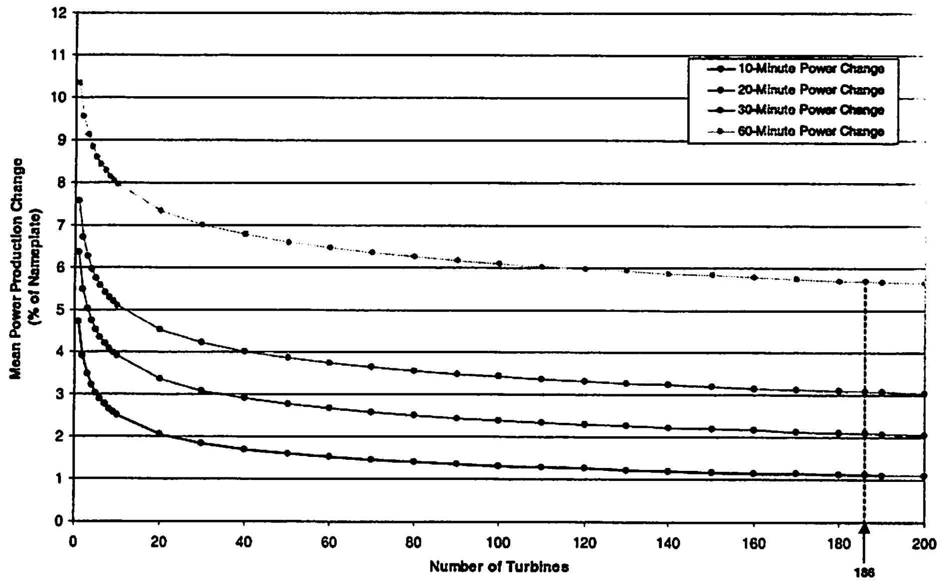
Truewind

Propagation of Gusts Through a Wind Farm



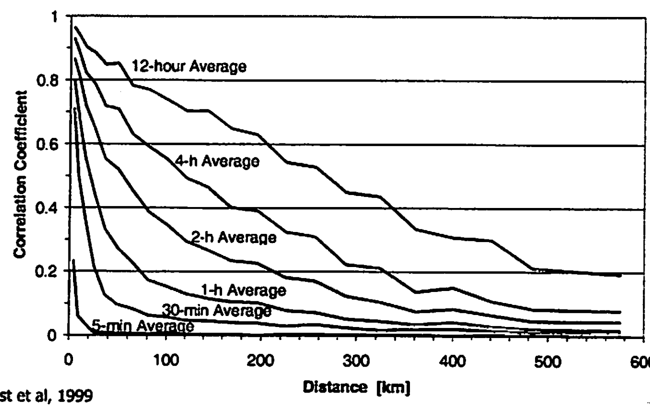
AWS Truewind

Mean Change in Power vs Number of Turbines at Flat Rock



Spatial Diversity of Turbine Output

Correlation coefficient of power change for different average times over the distance



From Ernst et al, 1999

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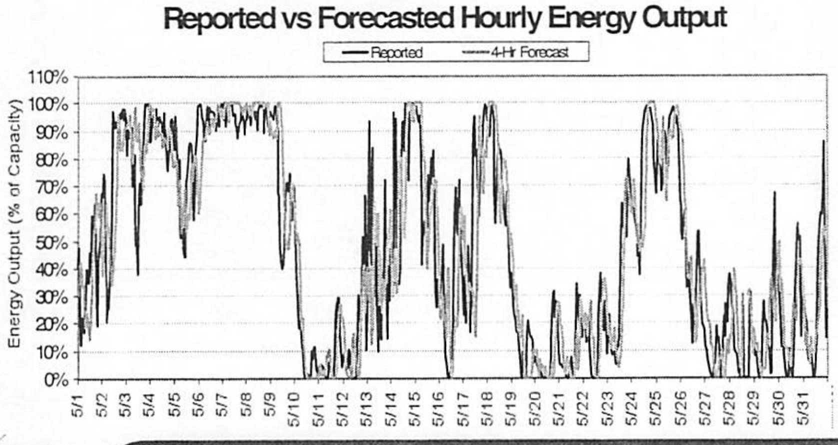
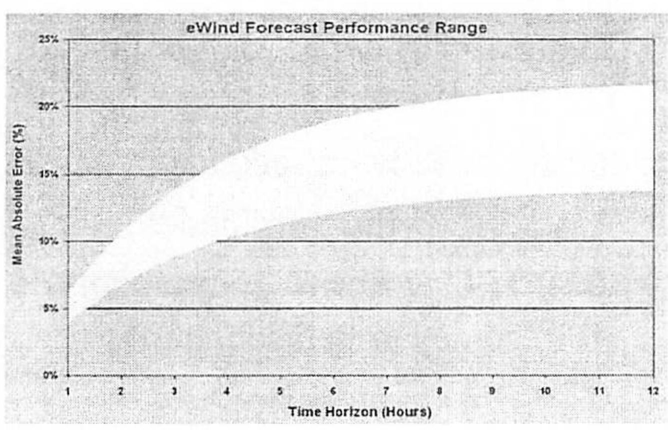
Typical 4-Hr PIRP Forecast Performance
San Gorgonio Pass, California - May 2003

Wind Forecasting



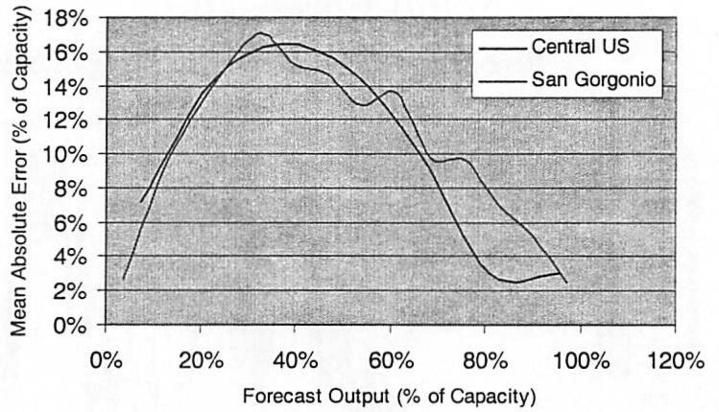
Forecast Accuracy Vs Time



AWS Truewind

Forecast Accuracy Vs Output

3-Hour Ahead Forecasts



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New York Integration Study

- Evaluating 3300 MW of wind on a 33,000 MW system
- Time scales from seconds to days
- AWS Truewind provided wind data
- GE PSEC performing grid analysis (from AGC to day-ahead scheduling)

AWS Truewind

NY Study: The Challenge

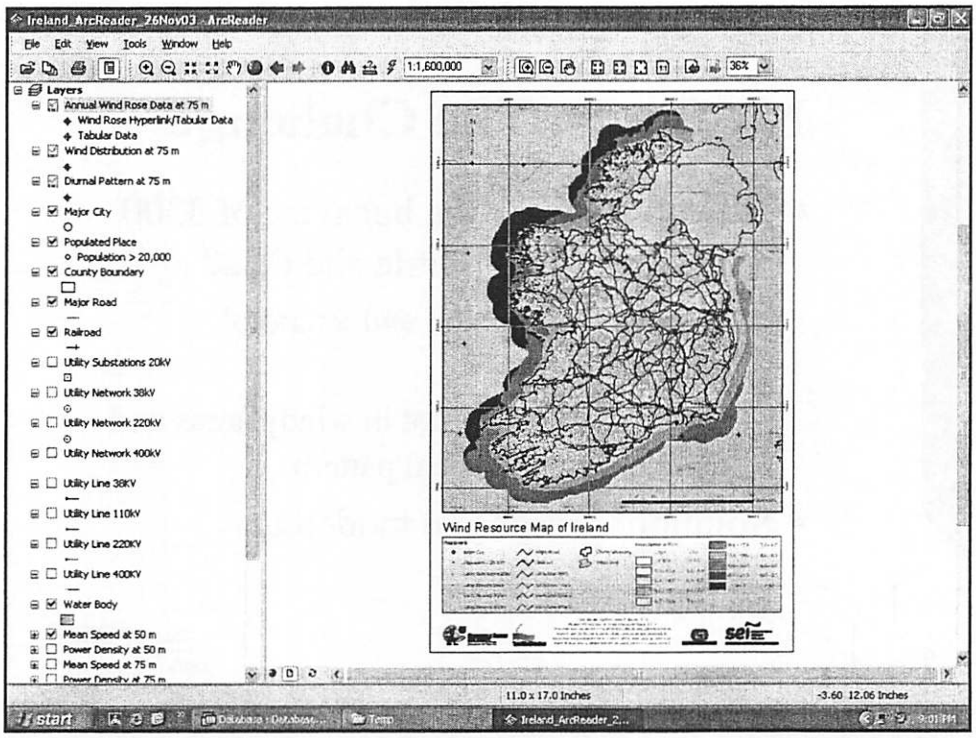
- How to simulate the behavior of 3300 MW of wind with little site data?
  - Must capture spatial and temporal correlations
  - Met stations often not in windy areas and exhibit wrong diurnal pattern
- Solution: Mesoscale modeling

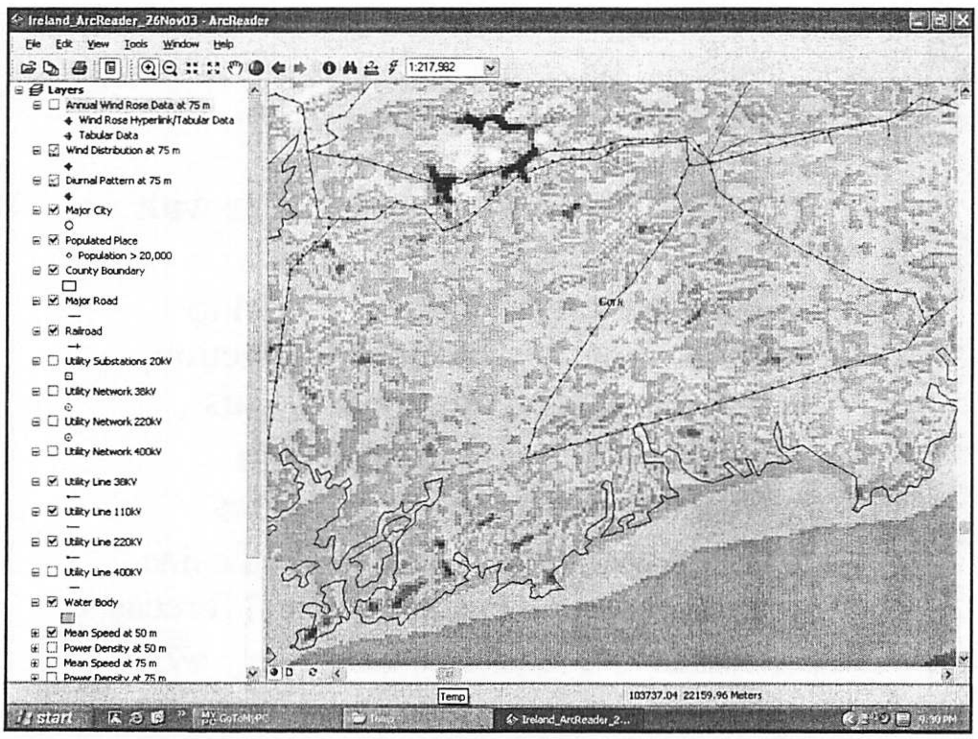
AWS Truewind

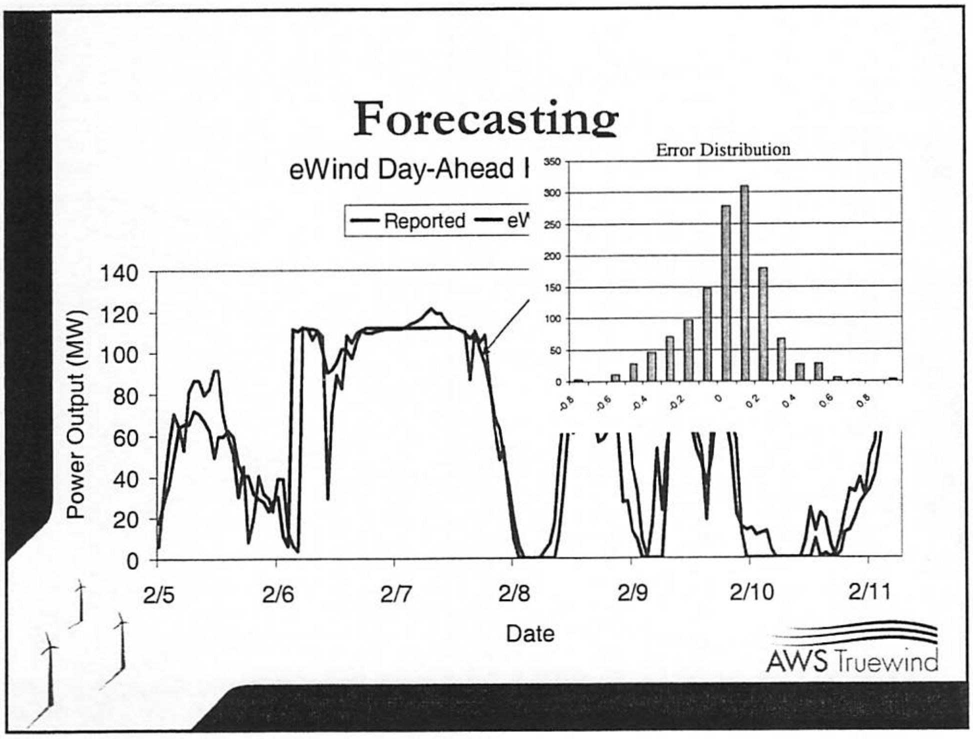
NY Study: Tasks

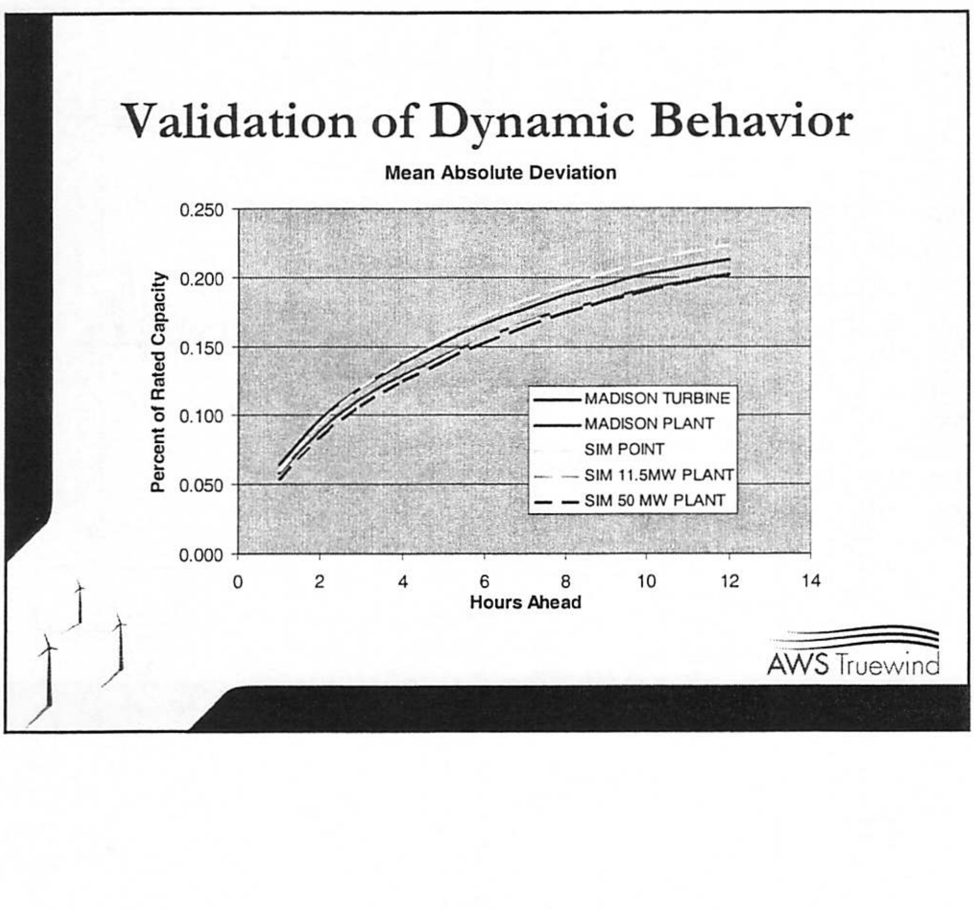
- Selected 33 potential project sites with 50-300 MW capacity
- Used a mesoscale weather model to simulate hourly wind speed, direction, temperature for 5 continuous years
- Sampled 1-min and 1-sec data to synthesize sub-hourly fluctuations
- Created statistical model to synthesize plant forecasts – based on actual forecasts

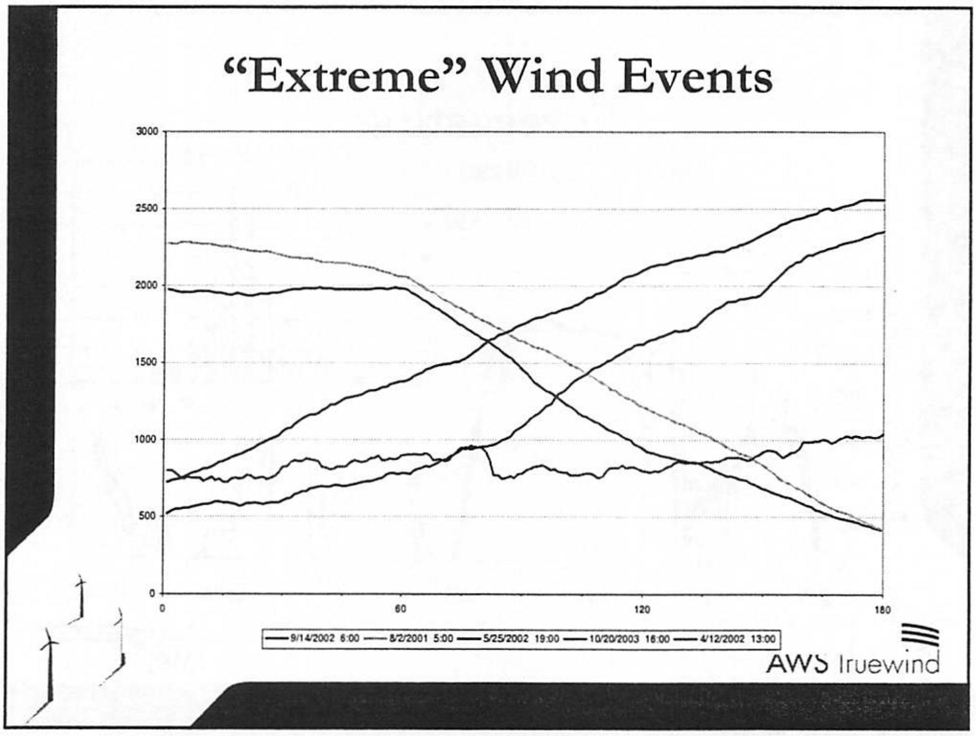
AWS Truewind

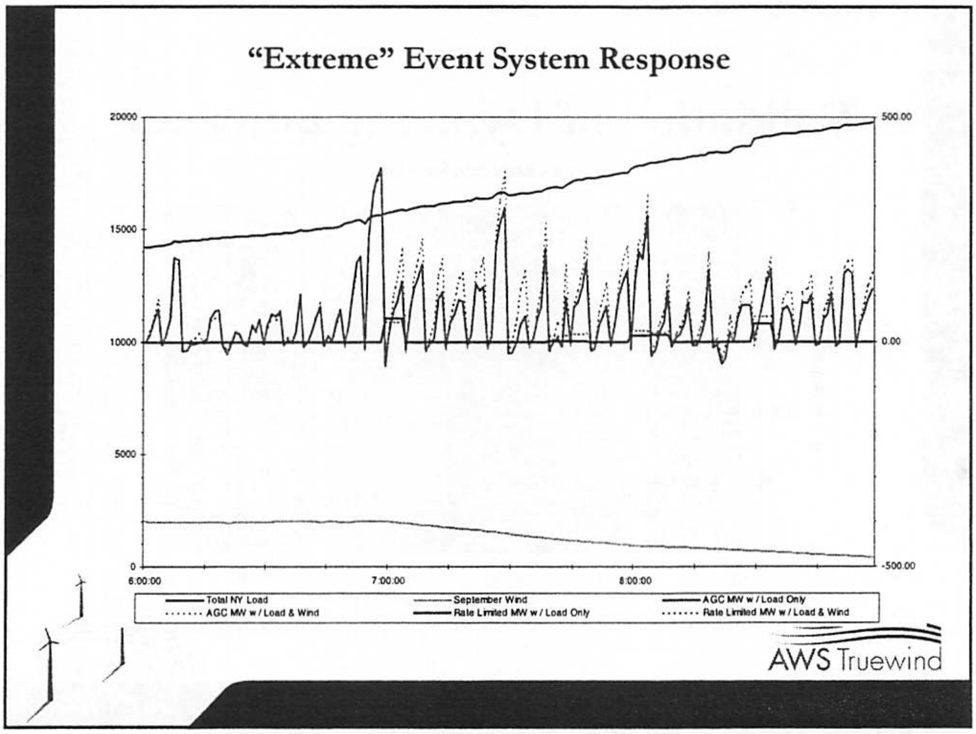

Ireland_ArcReader_26Nov03 - ArcReader
File Edit View Tools Window Help
1:1,600,000
36%
Layers
Annual Wind Rose Data at 75 m
Wind Rose Hyperlink/Tabular Data
Tabular Data
Wind Distribution at 75 m
Diurnal Pattern at 75 m
Major City
Populated Place
Population > 20,000
County Boundary
Major Road
Railroad
Utility Substations 20kV
Utility Network 38kV
Utility Network 220kV
Utility Network 400kV
Utility Line 38KV
Utility Line 110kV
Utility Line 220KV
Utility Line 400KV
Water Body
Mean Speed at 50 m
Power Density at 50 m
Mean Speed at 75 m
Wind Resource Map of Ireland
11.0 x 17.0 Inches
-3.60 12.06 Inches
start
Ireland_ArcReader_2...


Ireland_ArcReader_26Nov03 - ArcReader
File Edit View Tools Window Help
1:217,982
Layers
Annual Wind Rose Data at 75 m
Wind Rose Hyperlink/Tabular Data
Tabular Data
Wind Distribution at 75 m
Diurnal Pattern at 75 m
Major City
Populated Place
Population > 20,000
County Boundary
Major Road
Railroad
Utility Substations 20kV
Utility Network 38kV
Utility Network 220kV
Utility Network 400kV
Utility Line 38KV
Utility Line 110kV
Utility Line 220KV
Utility Line 400KV
Water Body
Mean Speed at 50 m
Power Density at 50 m
Mean Speed at 75 m
Cork
Temp
103737.04 22159.96 Meters
start
Ireland_ArcReader_2...


Forecasting
eWind Day-Ahead
Reported
Error Distribution
Power Output (MW)
Date
2/5
2/6
2/7
2/8
2/9
2/10
2/11
AWS Truewind


Validation of Dynamic Behavior
Mean Absolute Deviation
Percent of Rated Capacity
Hours Ahead
MADISON TURBINE
MADISON PLANT
SIM POINT
SIM 11.5MW PLANT
SIM 50 MW PLANT
AWS Truewind


"Extreme" Wind Events
3000
2500
2000
1500
1000
500
0
0
60
120
180
9/14/2002 6:00
8/2/2001 5:00
5/25/2002 19:00
10/20/2003 16:00
4/12/2002 13:00
AWS Truewind


"Extreme" Event System Response
20000
15000
10000
5000
0
500.00
0.00
-500.00
6:00:00
7:00:00
8:00:00
Total NY Load
September Wind
AGC MW w / Load Only
AGC MW w / Load & Wind
Rate Limited MW w / Load Only
Rate Limited MW w / Load & Wind
AWS Truewind

Conclusions

- Wind, turbine, and wind plant variability are not the same
- The more spatial diversity, the less temporal variability
- Mesoscale modeling provides a powerful tool for analyzing scenarios of large wind penetration

AWS Truewind

Voltage dip ride-through control of wind turbines with doubly-fed induction generator

Johan Morren[1)], Jan Pierik[2)], Sjoerd de Haan[1)]

[1)] Delft University of Technology
[2)] Energy research Centre of the Netherlands (ECN)
The Netherlands

IEA Topical Expert Meeting, 9-10 Nov. 2004, Dublin

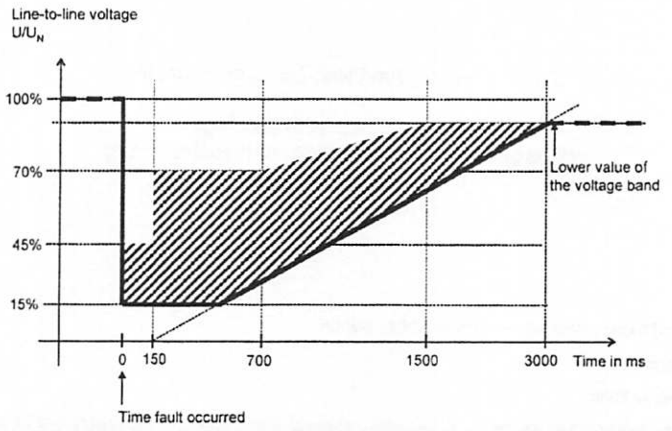
Johan Morren

25 November 2004

Introduction

- Increasing penetration
- Wind turbine - grid interaction
- Up to now: disconnection after fault
- Problem increases
- Grid connection requirements:
  - Stay connected
  - Support grid restoration

Introduction: Requirements for wind turbines



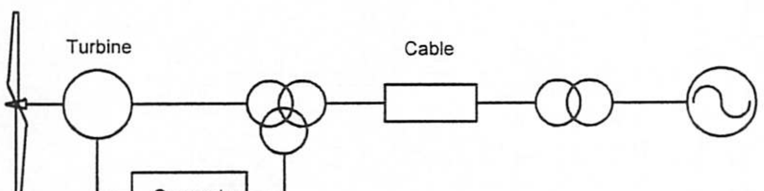
Introduction

- Introduction
- Model description
- Voltage dip behaviour without protection
- Protection
- Voltage dip behaviour with protection
- Discussion
- Conclusion

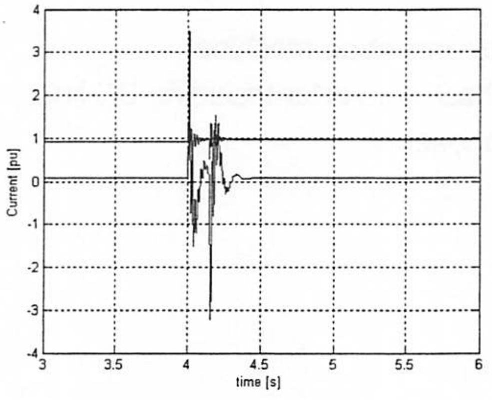
Modelling

- Fifth order induction machine
- Back-to-back converter including DC-link
- Grid components

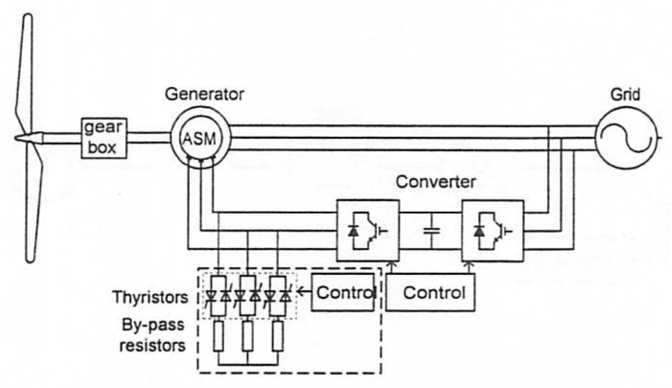
Modelling



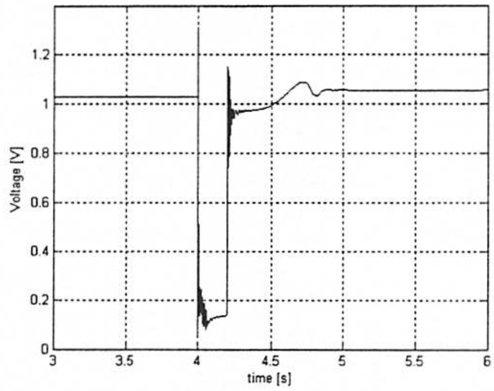
Voltage dip behaviour without protection



DFIG protection



Voltage dip behaviour: 85% - 0.2 sec.

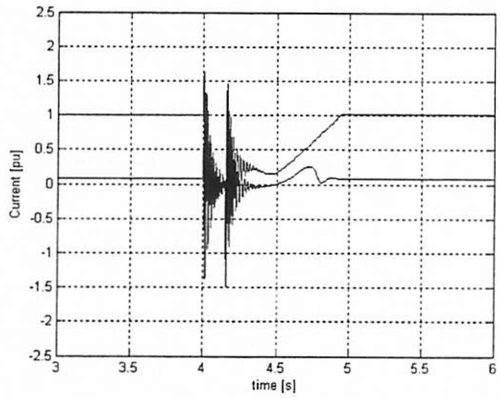


Grid voltage

25 November 2004 9

EPP TUDelft

Voltage dip behaviour: 85% - 0.2 sec.



Rotor current

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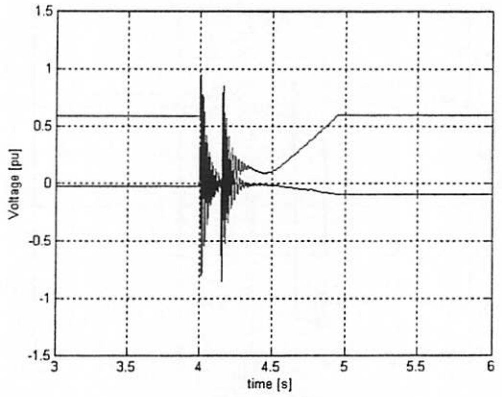
EPP TUDelft

Voltage dip behaviour: 85% - 0.2 sec.

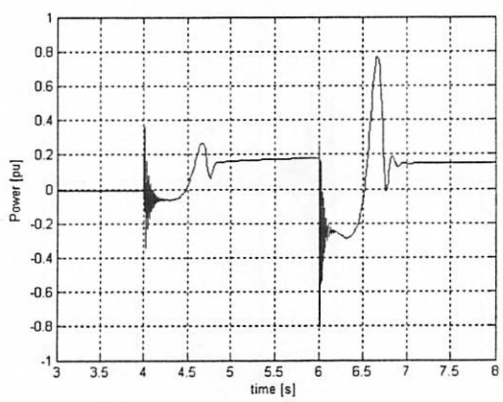


Rotor voltage

25 November 2004 11

EPP TU Delft

Voltage dip behaviour: 40% - 2 sec.

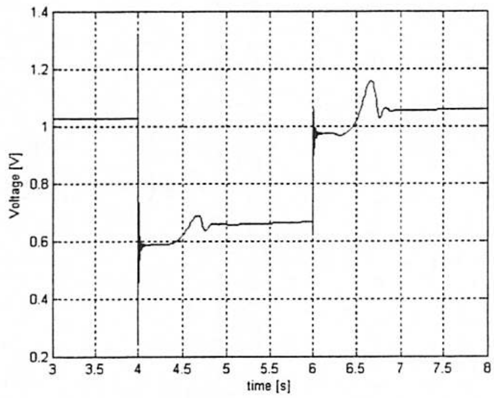


Reactive power

25 November 2004 12

EPP TU Delft

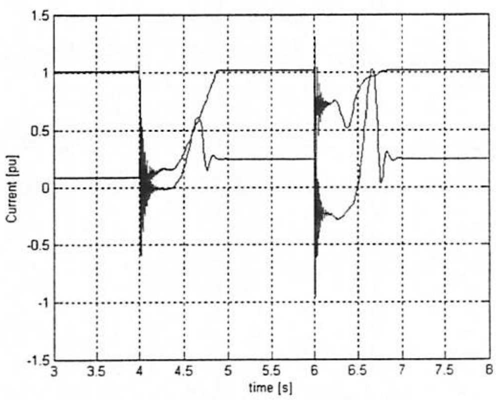
Voltage dip behaviour: 40% - 2 sec.



Grid voltage

EPP TUDelft

Voltage dip behaviour: 40% - 2 sec.



Rotor current

EPP TUDelft

Discussion

- Current oscillations
- Reactive power peaks
- Long dips: combination with pitch controller
- Use active power instead of reactive power

Conclusion

- Technique to keep DFIG connected to the grid during voltage dips
- Based on providing by-pass for rotor currents
- Turbine can resume normal operation after fault clearance
- Turbine can provide reactive power

More information

http://www.ecn.nl/library/
http://www.ecn.nl/library/reports/2004/c04050.html
http://www.ecn.nl/library/reports/2004/c04051.html

"On wind power system integration methods"

System Integration of Wind Turbines - Topical Expert Meeting"

Tuesday 9-10 November 2004, IEA Annex XI

Jury's Hotel, Ballsbridge, Dublin 4, Ireland

Lennart Söder

Professor in Electric Power Systems, KTH

Stockholm, Sweden

KTH Electrical Engineering

041109-LS1

If you really want to learn how something works – try to change it!

[someone]

KTH Electrical Engineering

041109-LS2

If you want to study the impact of wind power on power system, you first how to understand all power system operating rules and dimensioning standards and see if they are relevant and economic.

[Lennart Söder]

KTH Electrical Engineering

041109-LS3

The value of a power plant

- Operation cost value (incl. externalities)
- Capacity credit
- Control value
- Loss reduction value
- Grid investment value

KTH Electrical Engineering

041109-LS4

On the value of a power plant

There are:

- Physical value = true value = decreased system costs (including externalities)
- Market value = payment (cost for negative value) in market design

A good market design means:

- Physical value = Market value

KTH Electrical Engineering

041109-LS5

On integration cost of a power plant

The "integration cost" of a power plant is:

- Obtained as the difference in "physical value" between different power plants
- If "physical value ≠ "market value", then the difference corresponds to money transfer between actors.

Important factors are e.g.

- The replaced power plant (type and location)
- The rest of the system (controllability etc)

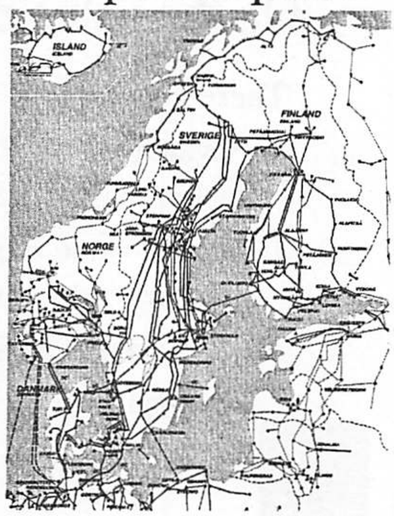
KTH Electrical Engineering

041109-LS6

On integration cost of a power plant

The "integration cost" of a power plant:

- Should be calculated with the same method, no matter the source



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On integration cost of power plants

Examples:

- SwePol Link caused grid investments in Sweden.
- New gas-power in Norway will cause grid investments both in Norway and Sweden.
- New Finnish nuclear power station will cause grid investments both in Finland and Sweden.
- Large investments of wind power in north Sweden will cause grid investments in Sweden.

KTH Electrical Engineering

041109-LS8

Integration cost – not only wind power

Finnish example:

- A new nuclear station of 1500 MW is planned.
- If it is suddenly stopped, a large part of the immediate replacement comes from Sweden-Norway
- The grid has therefore to be strengthen between Swe-Fin
- To be able to use the power, the export capability from Finland must be better, i.e., stronger lines in Sweden and/or new DC-line to Sweden.

KTH Electrical Engineering

041109-LS9

Integration of wind power

$$Maximal\ share\ of\ wind\ power = \frac{Maximal\ wind\ power}{Lowest\ consumption + possible\ \mathrm{exp}\,ort}$$

$$= (West - Denmark - 2001) = \frac{1930}{1400 + 2830} = 46\%$$

$$= (Gotland - 2001) = \frac{80}{45 + 180} = 36\%$$

$$= (ROI - 2005) = \frac{240 + 600}{1800 + 300} = 40\%$$

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041109-LS10

Challenges

- Design market so "integration costs" and values are included in market payment and grid tariffs
- Also include strengthening of national and trans-national grids.
- Otherwise the expansion of the power system will not be economically efficient

KTH Electrical Engineering

041109-LS11

Current KTH projects

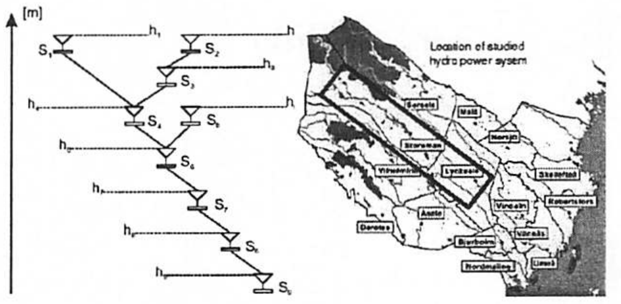
- Value of wind power in areas with limited export capability, Julija Matevosyan
- Regulating market bidding in systems with large amounts of wind power, Magnus Olsson
- Minimizing reserve market costs in multi-area markets at large amounts of wind power, Elin Lindgren

KTH Electrical Engineering

041109-LS12

Wind power in Ume river

- Wind power close to station S3
- Station S1+S2+S3+S3=250 MW = grid space



KTH VETENSKAP OCH KONST

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Wind power in Ume river

- Study of local balancing of wind power at grid problems
- 30-90 MW of wind power studied
- Market treatment discussed and evaluated

Table 6.2: Wind power spillage

Installed WP [MW]	Annual wind spillage out of possible production [%]	Hours of congestion No. (out of 8760)
30	1.5	149
60	4.5	361
90	7.3	581

KTH VETENSKAP OCH KONST

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041109-LS14

General comments

- "Maximal penetration of wind power" is mainly an economical issue
- **Not** a technical limit

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041109-LS15

Annex XXIV

Integration of Wind and Hydropower Systems

Brian Parsons
National Renewable Energy Laboratory

IEA Wind Implementing Agreement
November 2004

Topical Expert Meeting #41

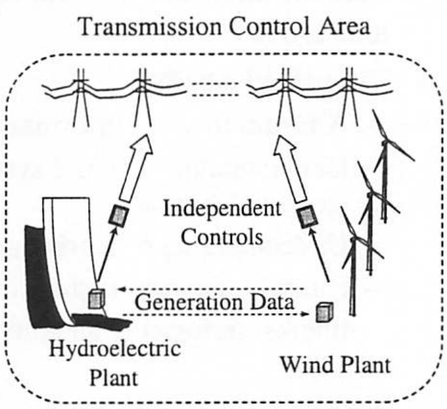
- Topic: Integration of Wind and Hydropower Systems
- Portland, Oregon, USA, November 5-6, 2003
- Participants: 28 persons from Canada, Norway, Sweden and USA
- Identified needs:
  - A forum to share information
  - Understanding of wind system impacts and costs on the electrical system
  - Understanding of market design and relation to wind integration
  - Quantify the benefits/detriments to the hydro system
  - Interest in forming an Annex or similar collaboration

Means to Achieve Objectives

- IEA countries: 450 GW hydro; 31+ GW wind (2003)
- Proposed annex research areas:
  - Grid Integration Case Studies
  - Hydrologic Impact Case Studies
  - Market and Economic Case Studies
  - Simplified Modeling of Wind-Hydro Integration Potential

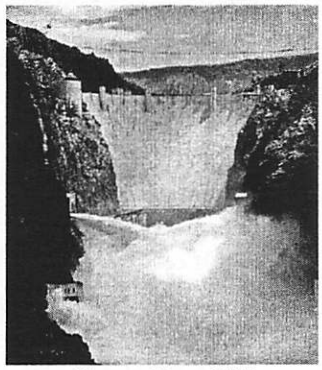
Status as Annex

- Approved by ExCo and IEA Legal
  - Soliciting country commitments
  - Kickoff meeting:
    - February 22-23, 2005
    - Boulder City, NV, USA
    - Hosted at Hoover Dam
  - Budget proposed



Participants

- Committed:
  - Australia
  - USA
- Probable/favorable:
  - Canada
  - Finland
  - Norway
  - Sweden
- Others possibly added later



Hoover Dam, USA

Status of Wind/Hydro Case Studies in the USA

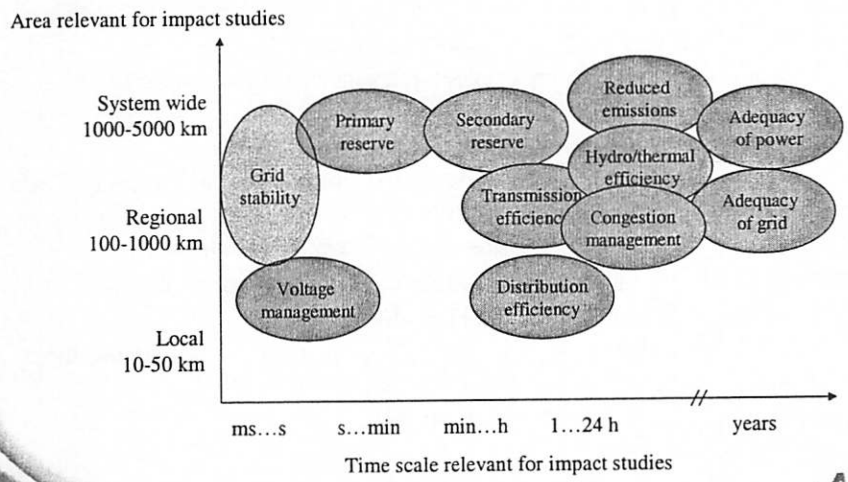
- **Missouri River Basin (2500 MW hydro, six dams)**
  - EnerNex, Wind-on-the-Wires, WAPA, USACE
  - Feasibility study underway; report expected 5/05
- **Lower Colorado River (2070 MW hydro, Hoover dam)**
  - Arizona Power Authority, B.Reclamation, WAPA, NREL,NAU
  - Pre-feasibility study complete 10/04
  - Feasibility study planned 1/05 through 6/06
- **Mid-Columbia River (2010 MW hydro, four dams)**
  - Grant County PUD, NREL, NAU
  - Contracting; start-up expected 10/04
- **Bonneville Power Administration – Columbia and Snake River Systems (17,460 MW hydro, 31 dams)**
  - Two wind/hydro integration product offerings; on-going analysis

Reports of Interest

- "Integrating Wind Energy with the BPA Power System: Preliminary Study," by E. Hirst, Sept. 2002.
  http://www.bpa.gov/power/pgc/wind/Wind_Integration_Study_09-2002.pdf
- "Wind-Hydropower Integration – Pre-feasibility Study Report," by the Arizona Power Authority, final report available October 2004. Report on the Lower Colorado River system study.

 1

Possible impacts of wind power on the electricity system



 2

Ideas for new Annex – System integration

- Scope: the impacts that require system-wide analyses
  - Leave out impacts that are dealt with locally: distribution efficiency, voltage management ?
  - Include market mechanisms / imbalance penalties for wind power ?
- Links:
  - CIGRE, UWIG, TSO involvement...
  - IEA Wind&Hydro (VTT, NREL)
  - IEA Dynamic models XXI (INETI, VTT)
  - Forecasting

VTT TECHNICAL RESEARCH CENTRE OF FINLAND

3

List of possible goals for new Annex – System integration

- State-of-the art: research made so far
- Guidelines for the study methods and data used
  - Input wind data: smoothing effect, relevant time scales and area
  - Stability analyses: models, study methods, ...
  - Reserves: combine varying wind and load, net imbalances
  - Energy system planning models: how to incorporate wind power in the models (uncertainty in different time scales)
  - Design rules used for systems, rules of thumb, new methods...
- Consensus : quantifying the impacts of WP on power systems
  - maximum penetration / cost for penetration
  - range of impacts/costs for different power systems; impact relative to system size, wind power dispersion, amount of flexibility
  - also integration methods: DSM, storages...
- Information exchange

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System integration of wind power – New Annex

- Time schedule:
  - plan to be presented for ExCo April-May 2005
  - start work October 2005...January 2006
  - 3 years
- Coordination costs of operating agent:
  - Total 84 000 euro for 3 years, 28 000 euro/year
    - Meetings, administration: 3 man-months (1 man-month/year)
    - Reporting: 3 man-months (1 man-month/year)
    - Travel costs 12 000 euro total (4000 euro/year)
- Cost of participating, if 6...10 participating countries
  - Yearly cost 2800...4700 euro/participant
  - Total cost 8400...14000 euro/participant

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VTT

Summary of IEA R&D Wind – 44th Topical Expert Meeting on

SYSTEM INTEGRATION OF WIND TURBINES

November 2004, Dublin, Ireland
Hannele Holttinen and Sven-Erik Thor

Background

Wind power penetration is increasing rapidly in many countries worldwide. In the countries currently leading the field in wind energy deployment, wind power capacity penetrations of up to 30% have been attained The interaction of wind energy and the power system has emerged as a potentially significant obstacle to increased penetration. There are issues ranging from operating reserves and frequency control, to the ability of the current grid system to accommodate additional generation. Individual countries with high wind power penetration may currently rely upon interconnection with neighboring countries for provision of ancillary services that support the high local penetration. As power systems and markets are not necessarily delineated by political boundaries, the technical assessment of the effects of high wind penetration upon these may better be carried out on a system-wide, rather than individual country, basis. In some cases the cost (both direct and external) of providing required ancillary services (including various classes of reserve) exhibits an exponentially increasing relationship with wind penetration. Thus, the availability of system ancillary services may be a limiting factor on the rate of deployment of wind power.

In addition to creating environmental benefits, it has been suggested that the nature of wind generation may impact on the operation of electricity systems in such a way as to increase the requirement for reserve. This is because wind generation has a number of physical and technical characteristics that are very different to the conventional generation it displaces.

Summary

The meeting gathered 28 participants, representing Denmark, Finland, Ireland, Italy, North Ireland, Norway, Portugal, Sweden, the Netherlands, UK and USA.

The meeting started with a presentation of the related IEA Annex XXI, Dynamic models of wind farms for power system studies. The following presentations covered both general descriptions of current situations in different regions and more detailed research presentations. Presentations were grouped in the following categories:

1. National presentations
2. Impacts of large scale on system operation
3. Dynamic simulation

List of mentioned topics/questions:

- Smoothing effects over large geographic areas
- How to calculate reserve requirements
- Ride through standards, is this possible
- Cost of integration has to be discussed for all energy sources, not only wind
- Reliable and validated models of wind turbines are required for power system analysis

Summary of discussion of a new annex

The discussion was preceded by a short presentation by Hannele Holttinen, VTT Finland, listing out some possible ideas for the new annex. See last presentation.

System integration of wind power is a large area of research, so the scope should be reduced. This could be done for example by taking only the impacts that require system-wide analyses, which would leave out impacts that are dealt with locally (distribution efficiency, voltage management). The goals could include:

- State-of-the art of research made so far
- Guidelines for the study methods and data used
- Quantifying the impacts of wind power on power system
- Information exchange between the participating countries and institutions

Guidelines could include study methods for stability analyses and reserve needs as well as how to incorporate wind power in grid analysis and energy system models. Rules of thumb that could be used as first step when considering large penetration of wind power in power systems would be useful. The annex should try to come up with quantification of the range of impacts and costs for different power systems (relative to system size, wind power dispersion, amount of flexibility).

The discussion was centred around defining the scope of the annex. Below is a short list of issues brought up in the discussion:

- Reducing the scope of the annex was considered essential.
- High penetration of wind power in the system is interesting. Definition of what is large amount of wind power is also needed (relative to installed generation capacity, consumed energy, interconnection capacity etc.)
- Larger areas are relevant, for example the Nordic system can trade reserves between the countries. System operation issues should be addressed in both the small systems, like Ireland, and the larger interconnected systems.
- Guidelines for input data for studies, especially how wind data is to be used was agreed to be useful
- Guidelines for methodologies for studies was considered more relevant than guidelines for which (commercial) models should be used.
- It should be noted that increasing other forms of energy also involve integration costs.
- Operating impact studies could be one major focus. Actual costs, not so much how the costs are implemented. List of best practices would be useful and possible to come up with (NREL/USA have already started).
- Recommendation on ideal features on market could be given (for in-depth market analyses, IEA group is not very suitable). With the wrong design of the market, the "integration cost" does not correspond to real system costs. The economic limits on wind penetration will depend upon how costs are allocated within a market, but the scope of the annex may become too broad if it includes consideration of market designs for large wind penetration.
- The effects and value of wind forecasting are important, especially for forecast horizon of 4–12 hours ahead. Wind power production forecast techniques as such should not be included in the scope of the proposed annex.

- Mitigation measures like DSM and storage: their role in helping to integrate high penetration of wind power is relevant to take up also in this annex, however, not as much detailed work as in other IEA Implementing agreements.
- This annex could end where the grid studies start. Stability analyses could be part of the annex, depending on for example where the reserves are taken (if reserves from different area, stability should be addressed).
- Limits to wind power penetration: there are no technical limits to how much wind power can be integrated, so the limits come from how much can be integrated at socially acceptable costs. Maximising the energy that can be delivered by wind in a power system is important. The ultimate objective could be to facilitate the highest economically feasible wind energy penetration within electricity power systems worldwide

The links to other ongoing work is very important to take into account in the proposed annex:

- Annex XXI Grid integration where models are tested and verified. Time scale division (second/minute versus 10minutes/hour) is not necessary, as the proposed annex has wider scope than models. Same participants in both two help to make this link work.
- Annex XXIV Wind and hydro: the proposed annex has a broader scope, also thermal systems. Most of the results from wind&hydro annex are relevant to this annex as well. Same participants in both two help to make this link work.
- CIGRE: workgroups do technical assessments, the same work should not be duplicated. System operation good focus in relation to that.
- ETSO link also important, like UWIG in USA (UWIG work will be linked to the proposed annex when USA participates in the annex)
- Other IEA implementing agreements than IEA R&D Wind: DSM, storages. This annex should not look into too detail on DSM and storages. However, their role in helping to integrate high penetration of wind power is relevant to take up also in this annex.

"System operation/ consequences with large amounts of wind power/high wind power penetration" were suggestions for the working name of the proposed annex, as the name should reflect that it is large amounts of wind power and "system operation" was preferred to "system integration". Planning aspect will not be excluded if the name is "operation".

It was decided to form an ad-hoc group to work further on the scope of the annex and make a draft proposal. The group is led by Hannele Holttinen/VTT (hannele.holttinen@vtt.fi) Finland and the following volunteered to participate: Jack Cadogan/DTI, USA; Ana Estanquero/Ineti, Portugal; Karsten Burges/ecofys, Holland; John McCann/SEI, Ireland and Lennart Söder/KTH, Sweden.

TSO participation in this annex was considered highly important and that would also help create a working link between Cigre and annex work.

List of participants

IEA R&D Topical Expert Meeting on System Integration

Ireland 9-10 November 2004

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Cancellation									
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