State-of-the-art of design and operation of power systems with large amounts of wind power - summary of IEA Wind collaboration

Hannele Holttinen,
Operating Agent, IEA WIND Task 25

IEA WIND Task 25

OBJECTIVE:
to analyse and further develop the methodology to assess the impact of wind on power systems

Started in 2006, duration 3 years. GOALS:

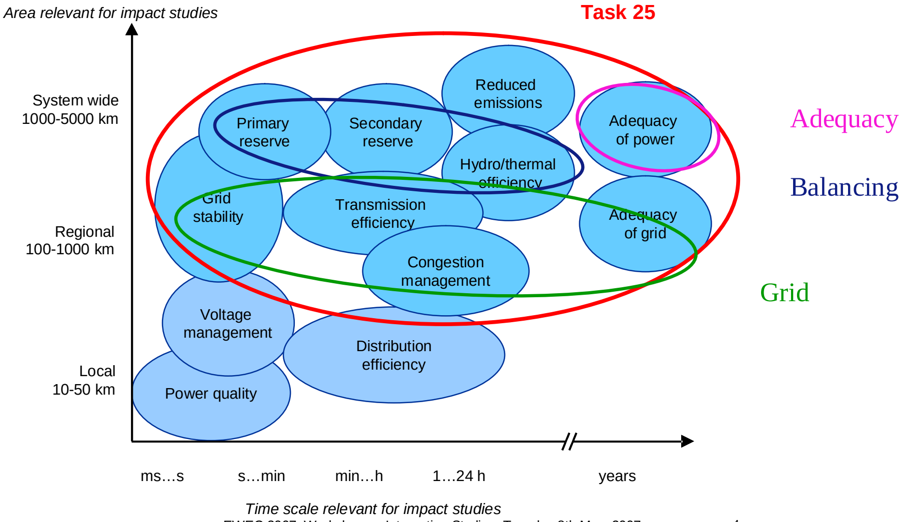
- Provide an international forum for exchange of knowledge
- State-of-the-art: review and analyse the studies and results so far
  - methodologies and input data, system operation practices, planning methodologies and modifications that have been necessary with high penetration, concepts and technologies enabling enhanced penetration
- Formulate guidelines:
  - recommended methodologies and input data when estimating impacts and costs of wind power integration
- Quantify the impacts of WP on power systems
  - range of impacts/costs; rules of thumb

www.ieawind.org

Integration costs

- Costs for power system for accommodating wind power
  - Not covered by wind power producers (investment costs for grid connection, …)
  - Part of the these costs may be allocated to wind power in some power systems (network charges, imbalance payments, …)
- Should be compared with the benefits of wind power
- Information needed for
  - Policymakers to ensure that the benefits of increasing wind energy will not be offset by negative impacts
  - System operators, regulators to ensure fair treatment of all producers: market design and rules, tariffs, allocation of costs

Wind power in the power system: impacts on reliability and efficiency



Task 25
Design and Operation of Power Systems with Large Amounts of Wind Power

Recent studies: levels of wind power studied

Nordic: 69 GW peak load, up to 20 GW wind (29 %)

UK: 65 GW peak, up to 26 GW wind (40 %)

Denmark: up to 100 % penetration

Ireland: 7 GW peak, up to 3.5 GW wind (54%)

Germany: 78 GW peak, up to 36 GW wind (46 %)

Netherlands: 16 GW peak, up to 6 GW wind (39 %)

Portugal: 10-12 GW peak, up to 5 GW wind (50 %)

Task 25
Design and Operation of Power Systems with Large Amounts of Wind Power

Recent studies in USA

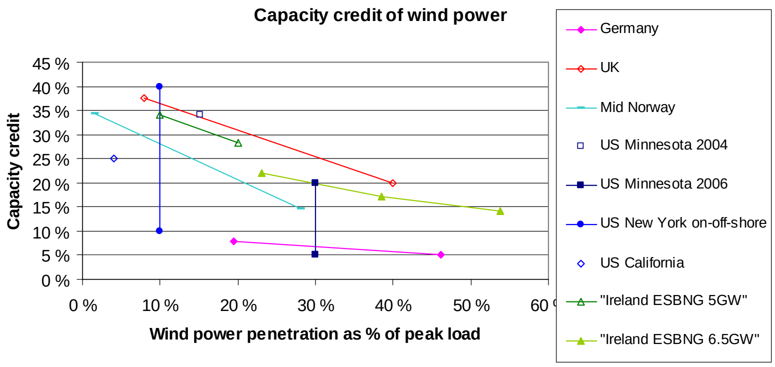
- Minnesota: 6000 MW of wind in 20 GW peak load system (=30 %)
- New York: 3300 MW of wind in 33 GW peak load system (=10 %)
- Colorado 1400 MW in 7 GW peak load system (=20 %)
- California: existing wind power, 4 % of peak load

Summary grid reinforcements

- UK : £50-100 / kW (70-140 €/kW) for 26 GW wind
- Netherlands : 60-110 €/kW for 6 GW offshore wind
- Portugal : 53 €/kW for 5.1 GW wind
- German dena study:100 €/kW for 36 GW wind

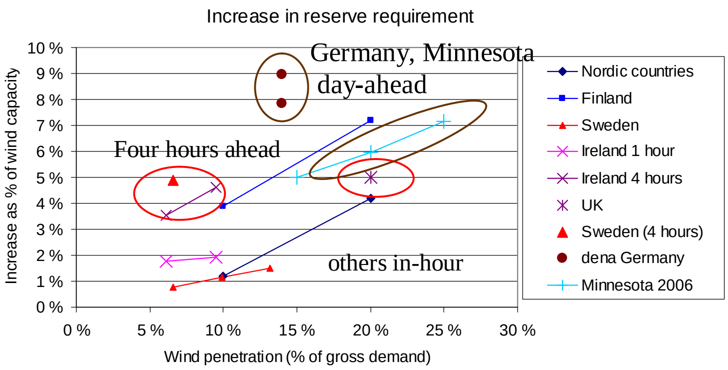
- Not comparable:
  - Depends on wind resource location versus load centres
  - Grid reinforcement costs are not continuous, there can be single very high cost reinforcements
  - The way that grid costs are allocated to wind power can differ:
    - Shallow/deep costs
    - Wind farm and power system interface

Summary capacity credit



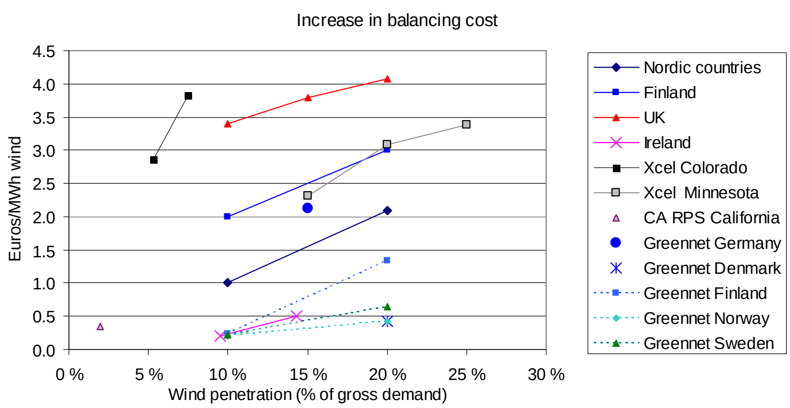
- Even if mainly energy resource, wind has a capacity value to power systems. However, at larger penetrations the value decreases. Value decreases faster for smaller areas.

Summary balancing requirements



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

Summary balancing costs



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

Current practise and recommendations for estimating wind integration costs

- Capture the smoothed out variability of wind power production time series for the geographic diversity assumed:
  - Actual data from tens of wind farms and/or met towers or synchronized weather simulation
  - Wind forecasting best practice for the uncertainty of wind power production.
- Examine wind variation in combination with load variations and production outages
- Capture system response through operational simulations
- Examine actual costs independent of tariff design structure

Best practices in grid integration of variable wind power: case studies from recent U.S. analyses and mitigation measures. ***J. Charles Smith, UWIG, US***

European Wind Integration Study EWIS for a successful integration of wind power into European electricity grids. *Wilhelm Winter, EWIS, Belgium*

The All Island Renewable Grid Study. *Mark O'Malley, University College Dublin, IR*

Assessment of existing constraints and solutions for high wind penetration in power systems. *Ana Estanqueiro, INETI, Portugal*

Integration state-of-the-art in Germany. *Cornel Ensslin, ISET, Germany*

Operational costs induced by fluctuating wind power production in Germany and Scandinavia. *Peter Meibom, Risoe National Laboratory, Denmark*

100% wind energy: consequences on market and system - study on a fictitious Western Danish power system. *Antje Orths, Energinet.Dk, Denmark*

Integration state-of-the-art in Sweden. *Lennart Söder, KTH, Sweden*

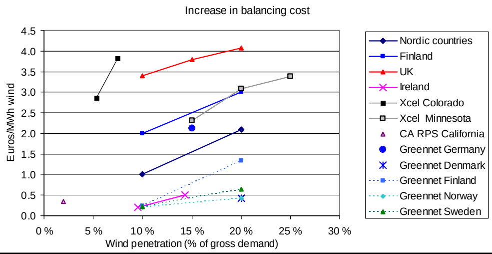
Imbalance costs of wind power for a hydro power producer in Finland. *H.Holttinen, VTT, Finland*

Impact of large scale wind power on system adequacy. *John Olav Tande, SINTEF, Norway*

Tradewind - further developing Europe's power market for large scale integration of wind power. *Frans Van Hulle, EWEA, Belgium*

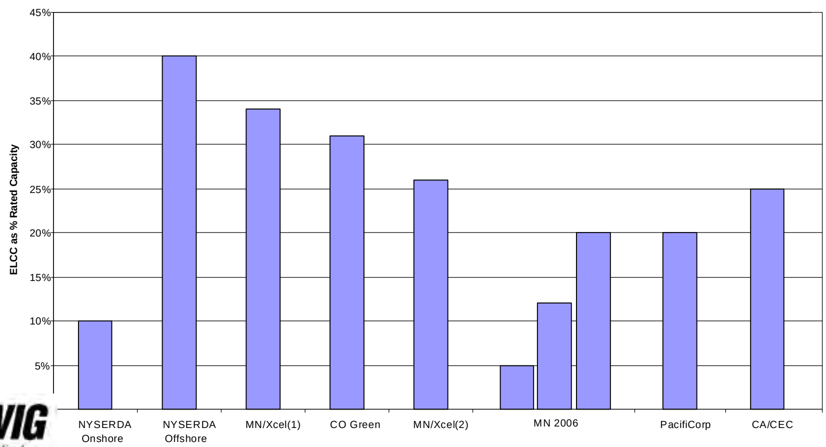
US (1) Comments on Balancing Results

- US studies – unit commitment time scale (day-ahead) costs included, identified as largest cost component
- Most recent Minnesota study (Dec 2006) shows reduction in balancing costs compared to 2004 study, at higher penetration level, due to:
  - Geographical diversity and control area consolidation
  - Access to hour-ahead and day-ahead MISO markets
  - Adequate transmission capacity



US (2) Comments on Capacity Credit Results

- Growing recognition of wind as energy resource vs. capacity resource, with some capacity value in planning studies
- Both simple and complex methods used to calculate ELCC



US (3) Wind Plant Integration Cost Summary

Ancillary Services Cost Comparison

Date	Study	Wind Capacity Penetration (%)	Regulation Cost ($/MWh)	Load Following Cost ($/MWh)	Unit Commit-ment Cost ($/MWh)	Gas Supply Cost ($/MWh)	Total Operating Cost Impact ($/MWh)
May 03	Xcel-UWIG	3.5	0	0.41	1.44	na	1.85
Sep 04	Xcel-MNDOC	15	0.23	na	4.37	na	4.60
Dec 06	MN/MNDOC	33	na	na	na	na	4.41
July 04	CA RPS Multi-year Analysis	4	0.45	na	na	na	na
June 03	We Energies	4	1.12	0.09	0.69	na	1.90
June 03	We Energies	29	1.02	0.15	1.75	na	2.92
2005	PacifiCorp	20	0	1.6	3.0	na	4.6
April 06	Xcel-PSCo	10	0.20	na	2.26	1.26	3.72
April 06	Xcel-PSCo	15	0.20	na	3.32	1.45	4.97

UWIG Utility Wind Integration Group

Best practices in grid integration of variable wind power: case studies from recent U.S. analyses and mitigation measures. *J. Charles Smith, UWIG, US*

European Wind Integration Study EWIS for a successful integration of wind power into European electricity grids. ***Wilhelm Winter, EWIS, Belgium***

The All Island Renewable Grid Study. *Mark O'Malley, University College Dublin, IR*

Assessment of existing constraints and solutions for high wind penetration in power systems. *Ana Estanqueiro, INETI, Portugal*

Integration state-of-the-art in Germany. *Cornel Ensslin, ISET, Germany*

Operational costs induced by fluctuating wind power production in Germany and Scandinavia. *Peter Meibom, Risoe National Laboratory, Denmark*

100% wind energy: consequences on market and system - study on a fictitious Western Danish power system. *Antje Orths, Energinet.Dk, Denmark*

Integration state-of-the-art in Sweden. *Lennart Söder, KTH, Sweden*

Imbalance costs and regulating power market impacts of wind power. *H.Holttinen, VTT, Finland*

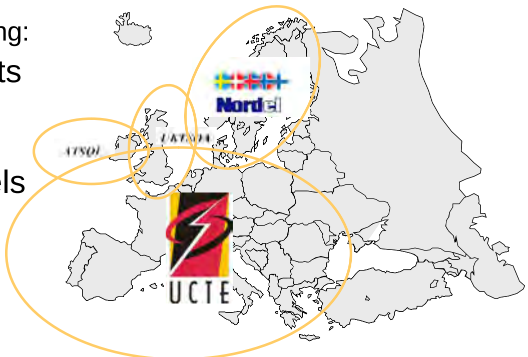
Impact of large scale wind power on system adequacy. *John Olav Tande, SINTEF, Norway*

Tradewind - further developing Europe's power market for large scale integration of wind power. *Frans Van Hulle, EWEA, Belgium*

EWIS – objectives of the study

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

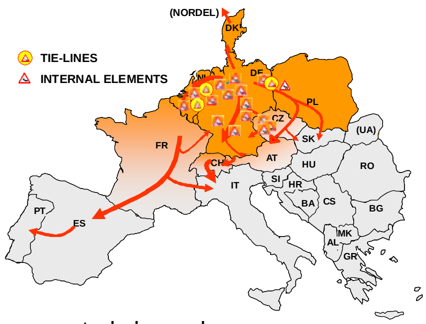
- operational/technical aspects including grid connection codes,
- market organizational models and procedures
- regulatory/market-related requirements,
- common public interest issues and even some political aspects impacting the integration of wind energy



European Wind Integration Study of European TSOs

EWIS – first phase results for risk mitigation

High wind power production causes regional overloading of transmission lines
After economic dispatch fundamental measures for risk mitigation are still necessary
Higher grid losses and reactive power demand in case of high wind power penetration



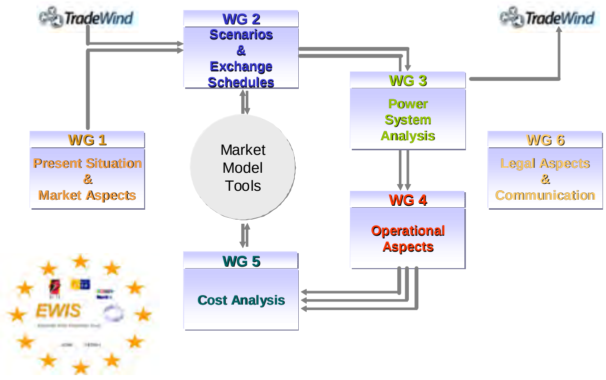
- Grid related measures
  - Corrective switching
  - Phase shifters
  - Further Grid re-enforcement realised by 2008

- Congestion Management
  - Reduction of cost effective power plants
  - Reduction of the daily auction capacity on congested channels

- Security Management (not taken into account by 2008)
  - Reduction of wind power generation due to system security reasons

EWIS – plan for second phase

- Phase II is started in May 2007 (time horizon 2015 including stability analysis)
  - Results available by 2009
    - Scenario development and cost analysis based on market modelling
  - Power system analysis and study of operational aspects for risk mitigation solutions



- Study supported by EC
- Involvement of stakeholders via Consultation Board
- Information exchange with Tradewind

Best practices in grid integration of variable wind power: case studies from recent U.S. analyses and mitigation measures. *J. Charles Smith, UWIG, US*

European Wind Integration Study EWIS for a successful integration of wind power into European electricity grids. *Wilhelm Winter, EWIS, Belgium*

The All Island Renewable Grid Study. *Mark O'Malley, University College Dublin, IR*

Assessment of existing constraints and solutions for high wind penetration in power systems. *Ana Estanqueiro, INETI, Portugal*

Integration state-of-the-art in Germany. *Cornel Ensslin, ISET, Germany*

Operational costs induced by fluctuating wind power production in Germany and Scandinavia. *Peter Meibom, Risoe National Laboratory, Denmark*

100% wind energy: consequences on market and system - study on a fictitious Western Danish power system. *Antje Orths, Energinet.Dk, Denmark*

Integration state-of-the-art in Sweden. *Lennart Söder, KTH, Sweden*

Imbalance costs of wind power for a hydro power producer in Finland. *H.Holttinen, VTT, Finland*

Impact of large scale wind power on system adequacy. *John Olav Tande, SINTEF, Norway*

Tradewind - further developing Europe's power market for large scale integration of wind power. *Frans Van Hulle, EWEA, Belgium*

All Island Renewable Grid Study

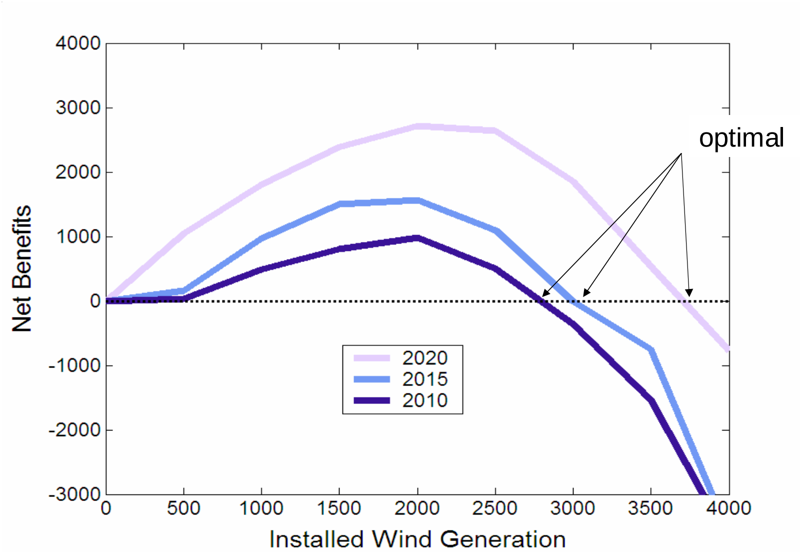
Work in progress

Mark O'Malley
Electricity Research Centre
University College Dublin, Ireland

http://ee.ucd.ie/erc/

8 May 2007

Net Benefits



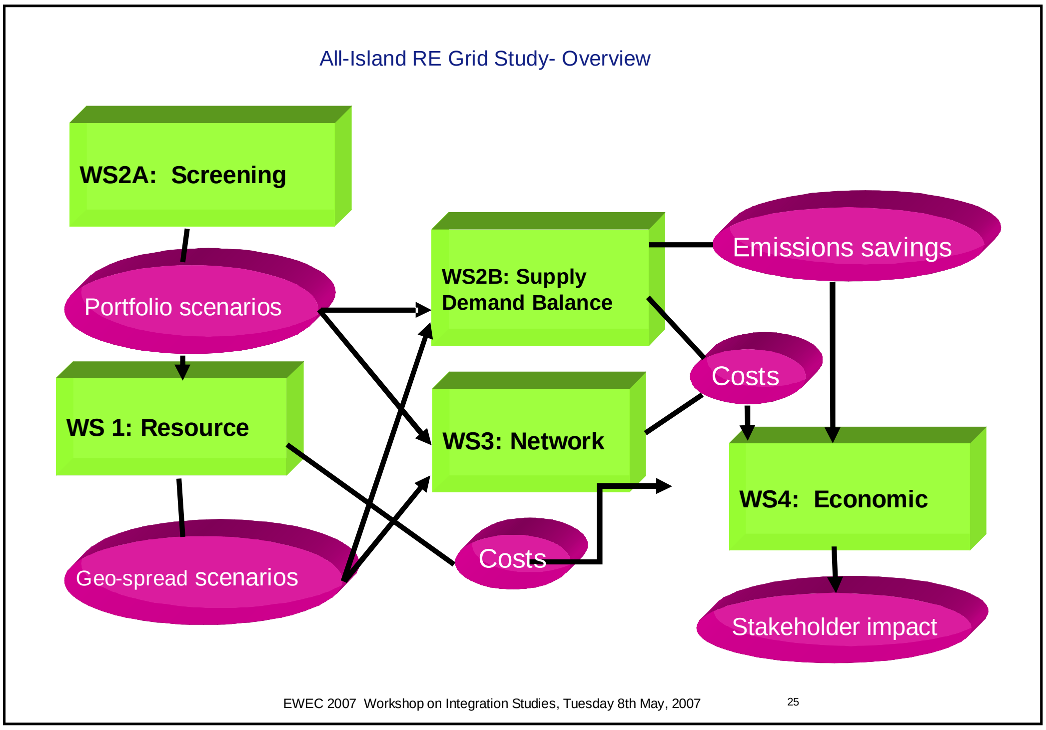
Denny, E. and O'Malley, M.J. "**Quantifying the Total Net Benefits of Grid Integrated Wind**", *IEEE Transactions on Power Systems*, Vol. 22, no. 2, 2007.

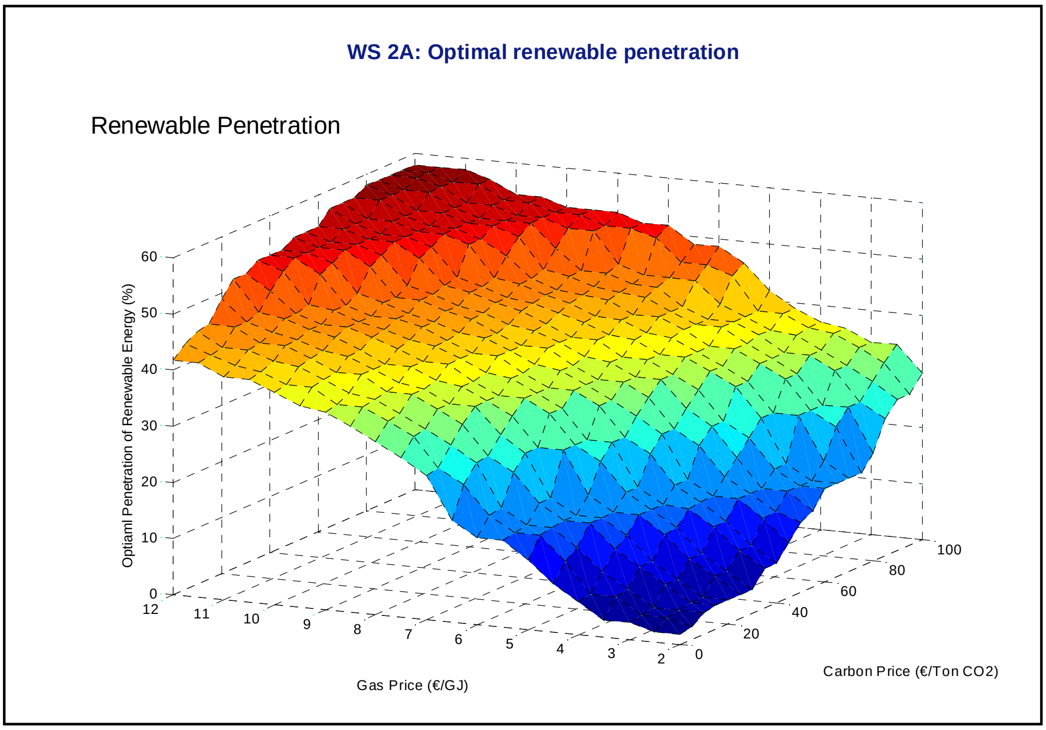
Previous Studies

- ILEX Energy, UCD, QUB and UMIST, “Operating reserve requirements as wind power penetration increases in the Irish electricity system”, Sustainable Energy Ireland,2004.
- ESB National Grid (EirGrid), “Impact of wind power generation in Ireland on the operation of conventional plant and the economic implications”, February, 2004.

All Island Renewable Grid Study

www.actionrenewables.org


All-Island RE Grid Study- Overview
WS2A: Screening
Portfolio scenarios
WS 1: Resource
Geo-spread scenarios
WS2B: Supply Demand Balance
WS3: Network
Costs
Emissions savings
Costs
WS4: Economic
Stakeholder impact
EWEC 2007 Workshop on Integration Studies, Tuesday 8th May, 2007
25


WS 2A: Optimal renewable penetration
Renewable Penetration
Optiaml Penetration of Renewable Energy (%)
Gas Price (€/GJ)
Carbon Price (€/Ton CO2)

Best practices in grid integration of variable wind power: case studies from recent U.S. analyses and mitigation measures. *J. Charles Smith, UWIG, US*

European Wind Integration Study EWIS for a successful integration of wind power into European electricity grids. *Wilhelm Winter, EWIS, Belgium*

Transmission investment for wind generation. *Goran Strbac, DG&SEE, UK*

The All Island Renewable Grid Study. *Mark O'Malley, University College Dublin, IR*

Assessment of existing constraints and solutions for high wind penetration in power systems. *Ana Estanqueiro, INETI, Portugal*

Integration state-of-the-art in Germany. *Cornel Ensslin, ISET, Germany*

Operational costs induced by fluctuating wind power production in Germany and Scandinavia. *Peter Meibom, Risoe National Laboratory, Denmark*

100% wind energy: consequences on market and system - study on a fictitious Western Danish power system. *Antje Orths, Energinet.Dk, Denmark*

Integration state-of-the-art in Sweden. *Lennart Söder, KTH, Sweden*

Imbalance costs of wind power for a hydro power producer in Finland. *H.Holttinen, VTT, Finland*

Impact of large scale wind power on system adequacy. *John Olav Tande, SINTEF, Norway*

Tradewind - further developing Europe's power market for large scale integration of wind power. *Frans Van Hulle, EWEA, Belgium*

Assessment of Existing Constraints and Solutions for High Wind Penetration in Power System

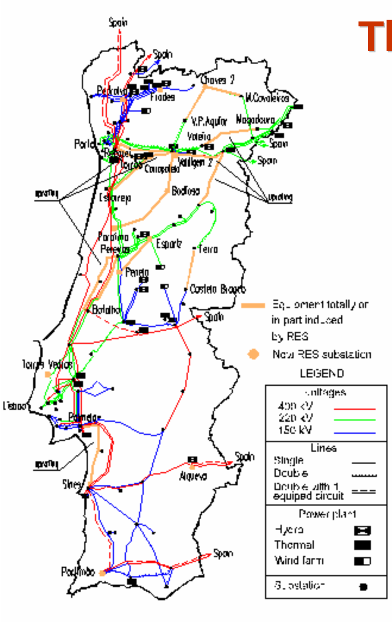
Ana Estanqueiro

[PT IEA Task 25 Advisory Group:
A. Estanqueiro (1), J. Ricardo(4), J. M. Ferreira de Jesus (2), J. Peças Lopes (3)]

(1) INETI - Instituto Nacional De Engenharia, Tecnologia E Inovação, I.P.
MINISTRY OF ECONOMY AND INNOVATION
(2) IST – Technical University Of Lisbon
(3) INESC-Porto, Faculdade De Engenharia Da Universidade Do Porto
(4) REN, Rede Eléctrica Nacional S.A. (Portuguese Transmission System Operator)

Milan, 8th of May, 2007

INETI



The Existing Network and the National Objectives

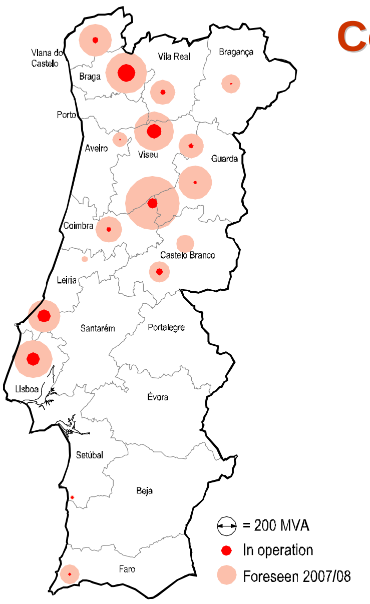
PT Goals on Wind Energy	
Capacity:	5100 MW
Capacity penetration:	~33%
Energy penetration:	~14 to 16 %

Existing Studies:

The PT TSO (REN) network planning division and UTL/IST initiated a transmission network (PTN) development planning study in 01 using:

- the sustainable wind resource;
- other national RES objectives, e.g. new large hydro power stations.

REN + REE are currently doing more studies on the Iberian transmission network



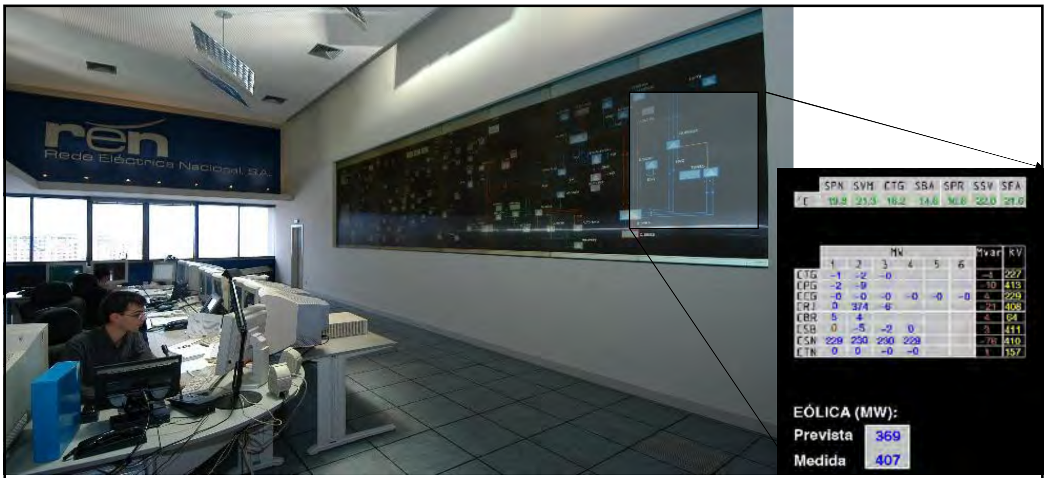
Common Technical Constraints

A. Limited grid capacity
- *as for all other power sources*

B. High variability of the resource
- *as for all non storable renewables;*

C. Non-adaptative/non-flexible power mix
- *e.g. reduced primary frequency capability (high percentage of nuclear or other base load generation);*

D. Conservative approach to the power systems design and operation, e.g:
- *Non-monitored "independent producers"*
- *Lack of distributed load/system management;*
- *Reduced DSG*



Solutions:

Innovative Characteristics of the Wind Systems and (also…) the Power System planned for Portugal

Innovative Characteristics of the Wind Power Plants

Innovative Characteristics of the Wind Power Plants and Power System Operation in Portugal

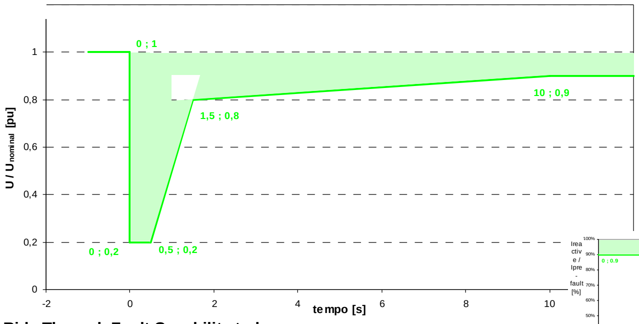
A
- **i.** **LVRFT - *Ride fault through* capability**
- **ii.** **Additional reactive power control: tg fi within [-0.2, +0.2];**
- **iii.** **Participation in the primary frequency control (95% of Popt);**

B
- **iv.** **Solutions for “wind/RES energy storage”: specially in articulation with hydropower + storage;**
- **v.** **Curtailment of wind production when anticipated (no-load periods);**

C
- **vi.** **Management of wind parks by clusters (“local wind power dispatch centers”);**

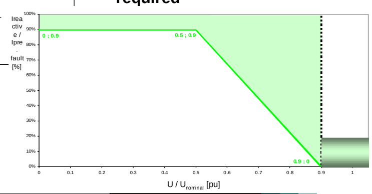
Innovative Characteristics of the Wind Power Plants

A. RTF capability + added reactive (minimum requirement in the current 1500 MW call)



Ride Through Fault Capability to be soon included in the Portuguese Grid Code

Reactive power contribution required



Innovative Characteristics of the Power System Operation

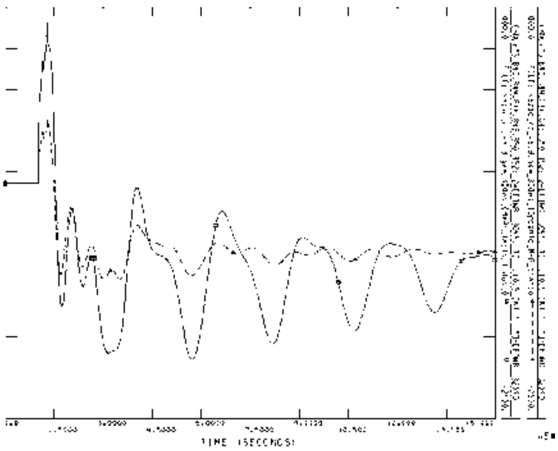
B. New equipments

Phase-shift autotransformer

to "force" wind power injected in 150 or 220 kV levels (or 60 kV DN) to flow to 400 kV grid, avoiding new HV lines.

still, and also possible to install FACTS

help to prevent the disconnection of large amounts of wind power for under voltage protection relays actuation; contributes to the damping of the oscillations.



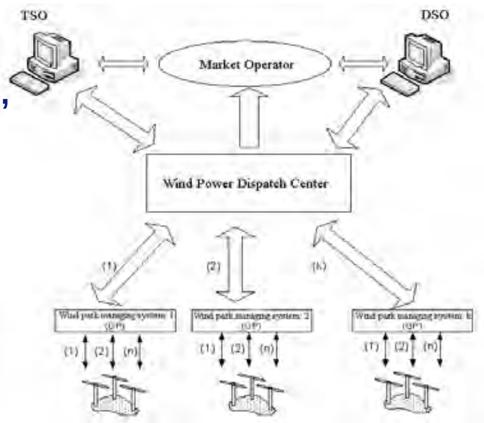
Innovative Characteristics of the Power System Operation

C. New strategies and equipments (next phase):

Installation of Wind Generation Dispatch Centres, acting as;

"Generation Aggregation Agents"

the forecasted wind power dispatch centres will enable to monitor and adapt the wind production injection to the network operating conditions without compromising security operational levels.



INETI

Best practices in grid integration of variable wind power: case studies from recent U.S. analyses and mitigation measures. *J. Charles Smith, UWIG, US*

European Wind Integration Study EWIS for a successful integration of wind power into European electricity grids. *Wilhelm Winter, EWIS, Belgium*

Transmission investment for wind generation. *Goran Strbac, DG&SEE, UK*

The All Island Renewable Grid Study. *Mark O'Malley, University College Dublin, IR*

Assessment of existing constraints and solutions for high wind penetration in power systems. *Ana Estanqueiro, INETI, Portugal*

Integration state-of-the-art in Germany. *Cornel Ensslin, ISET, Germany*

Operational costs induced by fluctuating wind power production in Germany and Scandinavia. *Peter Meibom, Risoe National Laboratory, Denmark*

100% wind energy: consequences on market and system - study on a fictitious Western Danish power system. *Antje Orths, Energinet.Dk, Denmark*

Integration state-of-the-art in Sweden. *Lennart Söder, KTH, Sweden*

Imbalance costs of wind power for a hydro power producer in Finland. *H.Holttinen, VTT, Finland*

Impact of large scale wind power on system adequacy. *John Olav Tande, SINTEF, Norway*

Tradewind - further developing Europe's power market for large scale integration of wind power. *Frans Van Hulle, EWEA, Belgium*

Integration State-of-the-Art in Germany

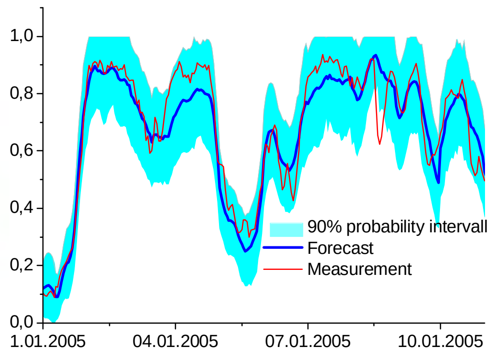
Focus: "Concepts and Technologies enabling enhanced Penetration"

Cornel Ensslin, ISET
Bernhard Ernst, RWE Transportnetz Strom
Lutz Hofmann, E.ON Netz

- **Offshore integration**
- **Intra-day market integration**
- **National wind balance**
- **Advanced forecasting**
- **Next-generation Integration Studies**

National Balance and Advanced Wind Power Forecasting

Wind power balance between control zones (15min interval)



Advanced wind power forecast for TSO

- **Ensemble forecasts**
- **Uncertainty probability**
- **Short-term forecasts for intra-day trading**

Intra – Day Platform – Characteristics

RWE

- At the moment hourly products tradable **75min** before fulfilment
- Open Order book
- Trading partner is respectively EEX
- Automatic matching or direct „double-click" of an order
- Prearranged order / OTC possible
- Clearing with EEX

Intra – Day Platform – Experience so far

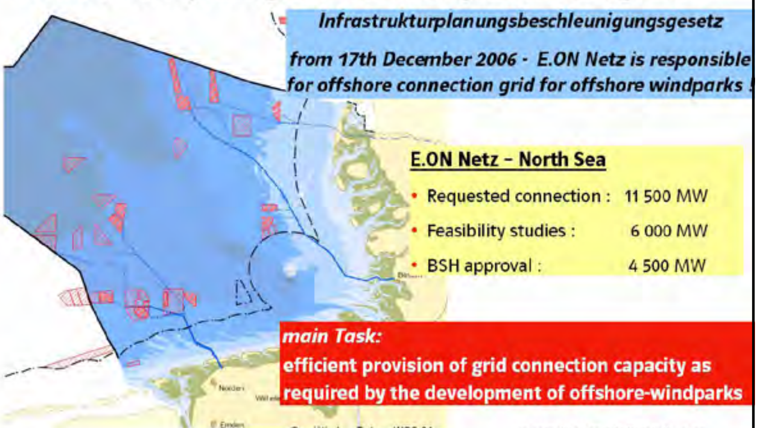
- Start of EEX Intra – Day Platform at **25.09.06**
- Average trade volume: round about **2.0 GWh** per day
- Maximum trade volume: over **5 GWh** on a day
- Currently licensed Participants : **80**
- High sophisticated scheduling by EEX, no problems at all.
- Possibility of the "after day" nomination is used by the market participants.

RWE Transportnetz Strom • ETE-S-P • 17.04.2007 2

Offshore integration

e·on Netz Dr. Hofmann, Network Planning

Offshore windpower grid connection systems – at a glance



Source: BSH

Offshore integration

e·on Netz Dr. Hofmann, Network Planning

Efficient provision of grid connection capacity for offshore wind

- **Main Task (1):** requested capacity is contradicted by respective offshore-projects planning status as well as the availability of relevant components and facilites
  - ⇒ E.ON Netz organised comprehensive capacity assessment and estimation system in order to provide an efficient connection system according to realistic demand requirement
- **Main Task (2):** technical perspective - technology-screening with focus on: grid concept, AC-Offshore-grid, DC-transmission grid/HVDC-technology, Offshore-construction technique, project execution/manufacturer capacities
- **Main Task (3):** Grid connection regulations and Grid Code Requirements – Provision of clear design criterias for windfarm developers
  - ⇒ Analysis of grid connection concepts at hand and derivation of sea-sided requirements
  - ⇒ Formulation of universal grid connection requirements and Compliance-Monitoring

Next-generation Integration Studies

Focus on Concepts and Technologies enabling enhanced Penetration

IAWT, FGH, ISET 2007: "Assessment of optimisation potentials for wind power integration into the transmission system":

§ **Optimisation of grid operation, e.g. by application of 'dynamic rating'**
§ **Accelerated grid extensions**
§ **Enhancement of grid codes for wind farm grid connection**
§ **Provision of ancillary services by wind turbines**
§ **Application of generation management to reduce reserve and balance demand**
§ **Application of demand-side measures and storage technologies.**

Funded by BMU (German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety).

dena-grid study II:
Integration of Renewable Energies into the German
Electricity Supply in the period 2015-2020
(Start 04/2007)

Best practices in grid integration of variable wind power: case studies from recent U.S. analyses and mitigation measures. *J. Charles Smith, UWIG, US*

European Wind Integration Study EWIS for a successful integration of wind power into European electricity grids. *Wilhelm Winter, EWIS, Belgium*

Transmission investment for wind generation. *Goran Strbac, DG&SEE, UK*

The All Island Renewable Grid Study. *Mark O'Malley, University College Dublin, IR*

Assessment of existing constraints and solutions for high wind penetration in power systems. *Ana Estanqueiro, INETI, Portugal*

Integration state-of-the-art in Germany. *Cornel Ensslin, ISET, Germany*

Operational costs induced by fluctuating wind power production in Germany and Scandinavia. *Peter Meibom, Risoe National Laboratory, Denmark*

100% wind energy: consequences on market and system - study on a fictitious Western Danish power system. *Antje Orths, Energinet.Dk, Denmark*

Integration state-of-the-art in Sweden. *Lennart Söder, KTH, Sweden*

Imbalance costs of wind power for a hydro power producer in Finland. *H.Holttinen, VTT, Finland*

Impact of large scale wind power on system adequacy. *John Olav Tande, SINTEF, Norway*

Tradewind - further developing Europe's power market for large scale integration of wind power. *Frans Van Hulle, EWEA, Belgium*

DTU

RISØ

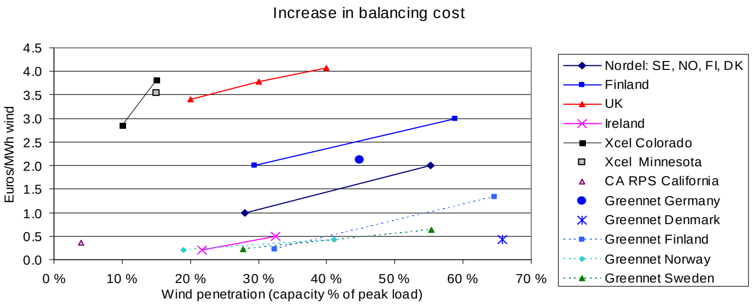
Operational costs induced by fluctuating wind po production in Germany and Scandin

Peter Meibom, Risoe National Laboratory, DTU
Christoph Weber, University Duisburg-Essen
Rüdiger Barth & Heike Brand, IER, University of Stuttgart

RISØ

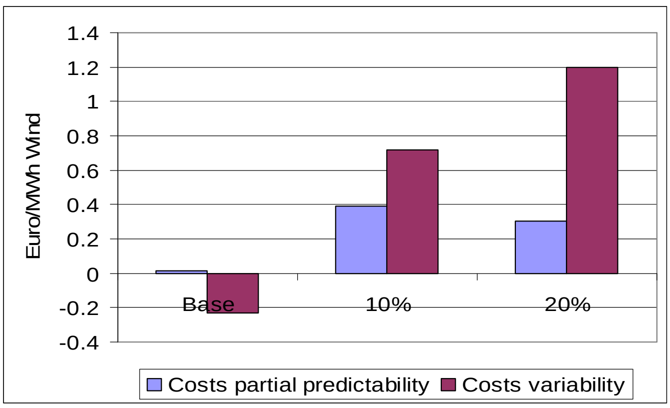
Greennet results

- Calculation with the Wilmar Planning tool (www.wilmar.risoe.dk)
- Why low values for increase in operational costs?
  - Hydro dominated regions (Norway, Sweden and Finland)
  - Exchange of secondary reserves between model regions allowed

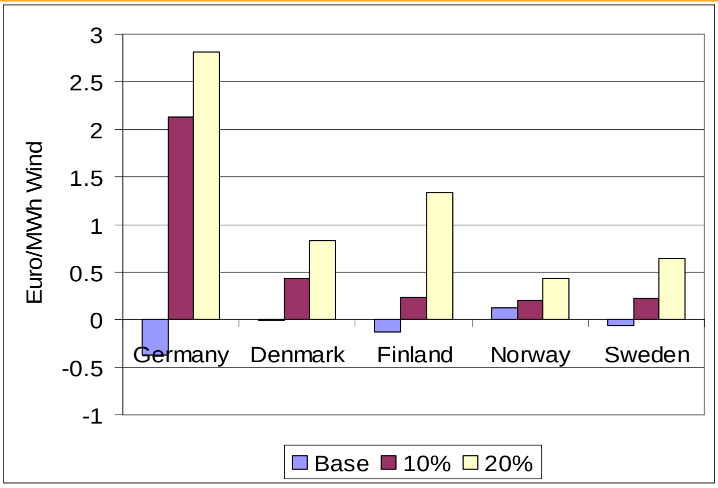


RISØ

Greennet results: Increase in system operation costs



Greennet results



Increase in system operation costs per MWh wind power production for the three wind cases and divided on countries.

Best practices in grid integration of variable wind power: case studies from recent U.S. analyses and mitigation measures. *J. Charles Smith, UWIG, US*

European Wind Integration Study EWIS for a successful integration of wind power into European electricity grids. *Wilhelm Winter, EWIS, Belgium*

The All Island Renewable Grid Study. *Mark O'Malley, University College Dublin, IR*

Assessment of existing constraints and solutions for high wind penetration in power systems. *Ana Estanqueiro, INETI, Portugal*

Integration state-of-the-art in Germany. *Cornel Ensslin, ISET, Germany*

Operational costs induced by fluctuating wind power production in Germany and Scandinavia. *Peter Meibom, Risoe National Laboratory, Denmark*

100% wind energy: consequences on market and system - study on a fictitious Western Danish power system. *Antje Orths, Energinet.Dk, Denmark*

Integration state-of-the-art in Sweden. *Lennart Söder, KTH, Sweden*

Imbalance costs of wind power for a hydro power producer in Finland. *H.Holttinen, VTT, Finland*

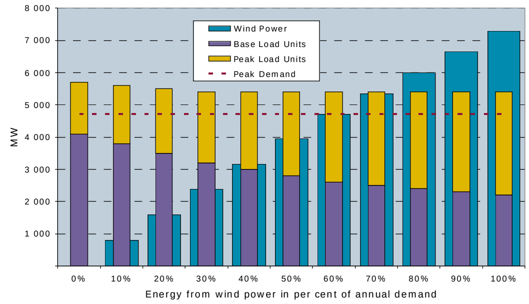
Impact of large scale wind power on system adequacy. *John Olav Tande, SINTEF, Norway*

Tradewind - further developing Europe's power market for large scale integration of wind power. *Frans Van Hulle, EWEA, Belgium*

Simulation of Fictitious Western Danish Power System

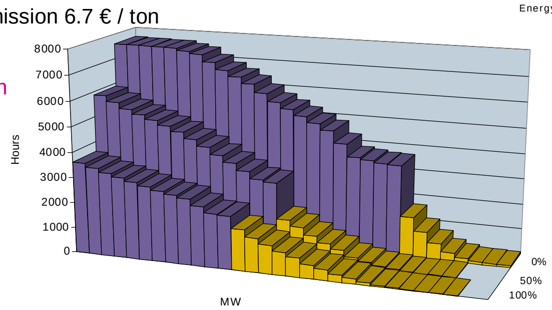
Assumptions:

- Isolated Power System
- Production Mix adjusted with:
  - Same Security of Supply
  - Coal Fired Base Load Units (Utilisation >2000 h/a)
  - Natural Gas Fired Peak Load Units (Utilisation <2000 h/a)
- Forced and Scheduled Outages included
- 5%, 30 years annuity=0,0651
- CO_2 Emission 6.7 € / ton



Production Mix

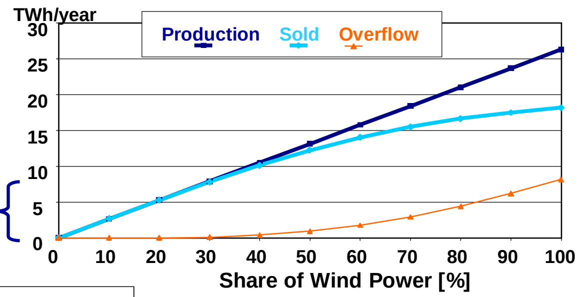
Utilization Time



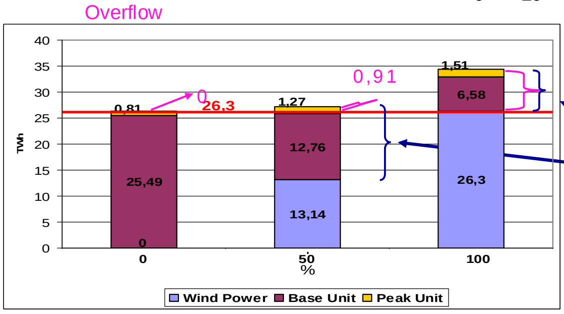
- Not considered:
  - ancillary services incl. regulating power
  - transmission capacity
  - network calculations
  - wind power installation cost

Residual Markets

Demand Side (~8 TWh)



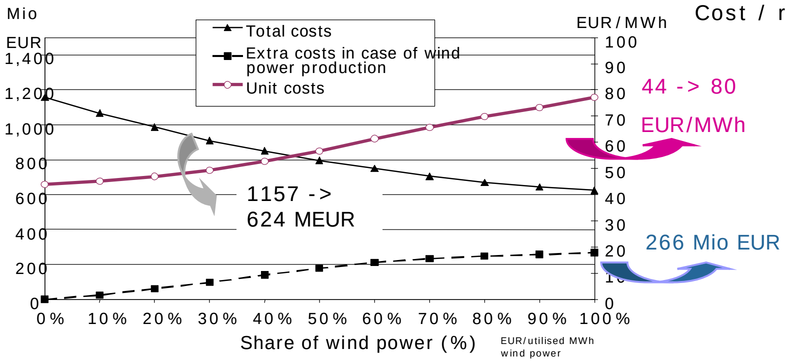
Energy Production, Consumption and Overflow



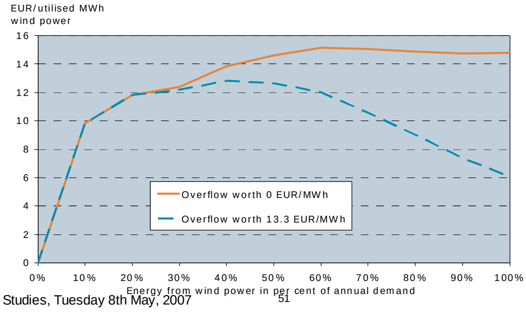
Production Side

Costs

Cost / residual production



- spec. fuel consumption:
  ~7.7 -> 8,3 GJ/ MWh
- CO2 emission:
  19 Mio t -> 6 Mio t



Additional costs
per % wind power

ENERGINET.DK

EWEC 2007 Workshop on Integration Studies, Tuesday 8th May, 2007 51

Lessons learned

- Configuration of power plant park & utilization times of thermal units change
- Demand for peak load units increases
- The specific costs of the thermal power plants increase with increasing share of wind power
- Large wind power penetration leads to additional costs of
  6-15 €/MWh per utilised MWh wind power – depending on the value of overflow => challenge for design of new products e.g.:
- New demand types are needed to utilise the power overflow (e.g. heat pumps, electric boilers in district heating systems etc…..)

ENERGINET.DK

EWEC 2007 Workshop on Integration Studies, Tuesday 8th May, 2007 52

Best practices in grid integration of variable wind power: case studies from recent U.S. analyses and mitigation measures. *J. Charles Smith, UWIG, US*

European Wind Integration Study EWIS for a successful integration of wind power into European electricity grids. *Wilhelm Winter, EWIS, Belgium*

The All Island Renewable Grid Study. *Mark O'Malley, University College Dublin, IR*

Assessment of existing constraints and solutions for high wind penetration in power systems. *Ana Estanqueiro, INETI, Portugal*

Integration state-of-the-art in Germany. *Cornel Ensslin, ISET, Germany*

Operational costs induced by fluctuating wind power production in Germany and Scandinavia. *Peter Meibom, Risoe National Laboratory, Denmark*

100% wind energy: consequences on market and system - study on a fictitious Western Danish power system. *Antje Orths, Energinet.Dk, Denmark*

Integration state-of-the-art in Sweden. *Lennart Söder, KTH, Sweden*

Imbalance costs of wind power for a hydro power producer in Finland. *H.Holttinen, VTT, Finland*

Impact of large scale wind power on system adequacy. *John Olav Tande, SINTEF, Norway*

Tradewind - further developing Europe's power market for large scale integration of wind power. *Frans Van Hulle, EWEA, Belgium*

Results from Sweden - 1

- Publication of the PhD thesis *Wind power integration in power systems with transmission bottlenecks* by Julija Matevosyan.
- Shows benefits of coordinated operation of wind power and hydro power in areas with limited export capabilities
- Develops methods for optimal bidding of wind power to power exchanges.

Results from Sweden - 2

- New investigation started in Sweden: One aim is to:
- "Evaluate whether the current rules for renewable energy creates obstacles for a large scale expansion of renewable energy. If it is found that changes are required, then the investigation should propose such changes."
- The report will be finished on Dec 31, 2007.
- Within the study an international comparison will be made (how did they succeed to extend wind power in Germany and Spain etc)

Results from Sweden - 3

Grid tariffs is found to be important:

- Some grids have tariffs on producers, some on consumers, some on both.
- The needed tariff level depends on the economic value of the grid: Some companies uses value = "replacement cost", while others uses value = "original investment cost". The first method è 3 times higher value è 3 times higher tariffs.

Results from Sweden - 4

- The electricity market is international so harmonized grid tariffs are important.
- Wind power is often connected to regional and local grids, so harmonized tariffs on different voltage levels is also important.
- Now in Sweden: Different tariff structures è "Tariff lines" where it is profitable to erect a line just to reach a low-tariff part of the grid.
- In Germany grid tariff=0 for wind power. In Sweden it can be 0.8 Eurocent/kWh.
- The aim of the investigation is to analyze these problems.

Best practices in grid integration of variable wind power: case studies from recent U.S. analyses and mitigation measures. *J. Charles Smith, UWIG, US*

European Wind Integration Study EWIS for a successful integration of wind power into European electricity grids. *Wilhelm Winter, EWIS, Belgium*

The All Island Renewable Grid Study. *Mark O'Malley, University College Dublin, IR*

Assessment of existing constraints and solutions for high wind penetration in power systems. *Ana Estanqueiro, INETI, Portugal*

Integration state-of-the-art in Germany. *Cornel Ensslin, ISET, Germany*

Operational costs induced by fluctuating wind power production in Germany and Scandinavia. *Peter Meibom, Risoe National Laboratory, Denmark*

100% wind energy: consequences on market and system - study on a fictitious Western Danish power system. *Antje Orths, Energinet.Dk, Denmark*

Integration state-of-the-art in Sweden. *Lennart Söder, KTH, Sweden*

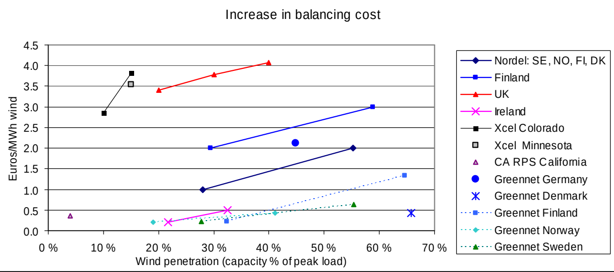
Imbalance costs of wind power for a hydro power producer in Finland. *H.Holttinen, VTT, Finland*

Impact of large scale wind power on system adequacy. *John Olav Tande, SINTEF, Norway*

Tradewind - further developing Europe's power market for large scale integration of wind power. *Frans Van Hulle, EWEA, Belgium*

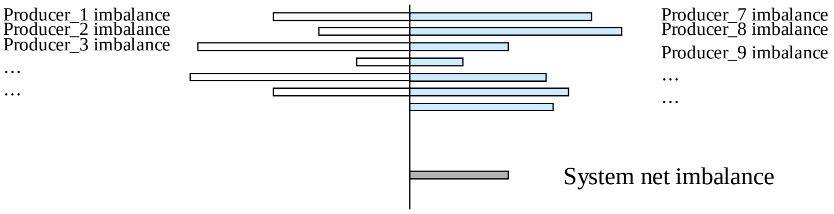
Costs for increased reserve requirements in Nordic countries – Holttinen Phd 2004

- 2-3 €/MWh for Finland, 1-2 €/MWh for Nordic
- Lower costs than UK, US, due to hourly variability impacts only
  - assumption: forecast errors dealt with updated forecasts
- Most of the cost comes from assuming new investments allocated to wind power – increased use of reserves less than third of costs
- Comparing Finland – Nordic shows the benefit of larger control areas, like Nordic system operated today



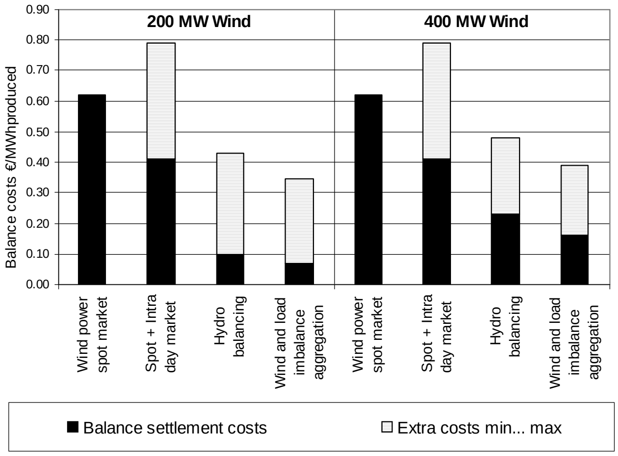
Balancing costs for wind power in Finland, data year 2004

- Imbalance costs from **day-ahead** forecasting **0.62 €/MWh**
  - 12 wind farms distributed along the West coast of Finland, forecast error 31 % of energy to balance settlement
  - Low balancing costs: large coordinated balancing market in Nordic power system - and low penetration wind, no effect on prices



Options for reducing balancing costs from day-ahead forecast errors. Case Finland, year 2004

- **Elbas intra-day market** to correct forecast errors 3 h before delivery:
  - Reduces costs only if trading close to spot market prices
- **Aggregating wind and 4000 MW load imbalances**
  - Reduces costs by 37-74 % for 400 MW wind
- **Internal balancing with 400 MW hydro**:
  - Reduces costs by 23-63 % for 400 MW wind
  - Market value of the balancing 1.31 €/MWh



Best practices in grid integration of variable wind power: case studies from recent U.S. analyses and mitigation measures. *J. Charles Smith, UWIG, US*

European Wind Integration Study EWIS for a successful integration of wind power into European electricity grids. *Wilhelm Winter, EWIS, Belgium*

The All Island Renewable Grid Study. *Mark O'Malley, University College Dublin, IR*

Assessment of existing constraints and solutions for high wind penetration in power systems. *Ana Estanqueiro, INETI, Portugal*

Integration state-of-the-art in Germany. *Cornel Ensslin, ISET, Germany*

Operational costs induced by fluctuating wind power production in Germany and Scandinavia. *Peter Meibom, Risoe National Laboratory, Denmark*

100% wind energy: consequences on market and system - study on a fictitious Western Danish power system. *Antje Orths, Energinet.Dk, Denmark*

Integration state-of-the-art in Sweden. *Lennart Söder, KTH, Sweden*

Imbalance costs of wind power for a hydro power producer in Finland. *H.Holttinen, VTT, Finland*

Impact of large scale wind power on system adequacy. *John Olav Tande, SINTEF, Norway*

Tradewind - further developing Europe's power market for large scale integration of wind power. *Frans Van Hulle, EWEA, Belgium*

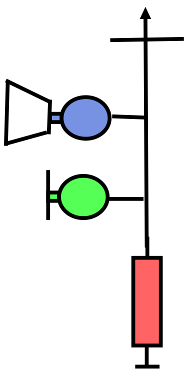
Impact of large scale wind power on system adequacy

John.O.Tande@sintef.no, SINTEF Energy Research, Norway

Introduction

- The impact of wind power on system adequacy is studied.
- The impact is assessed using data from a real life regional power system with a need for new generation to meet future demand increase.
- System adequacy is addressed considering the system's LOLP, i.e. the probability of the system not being able to supply the peak load.
- The capacity value of wind (or any other generation) is determined from the LOLP calculations as the load carrying capacity.

Case study system



Total import capacity
14 TWh / 1600 MW (4x400 MW)

13 TWh hydro / 2250 MW (6x375 MW)

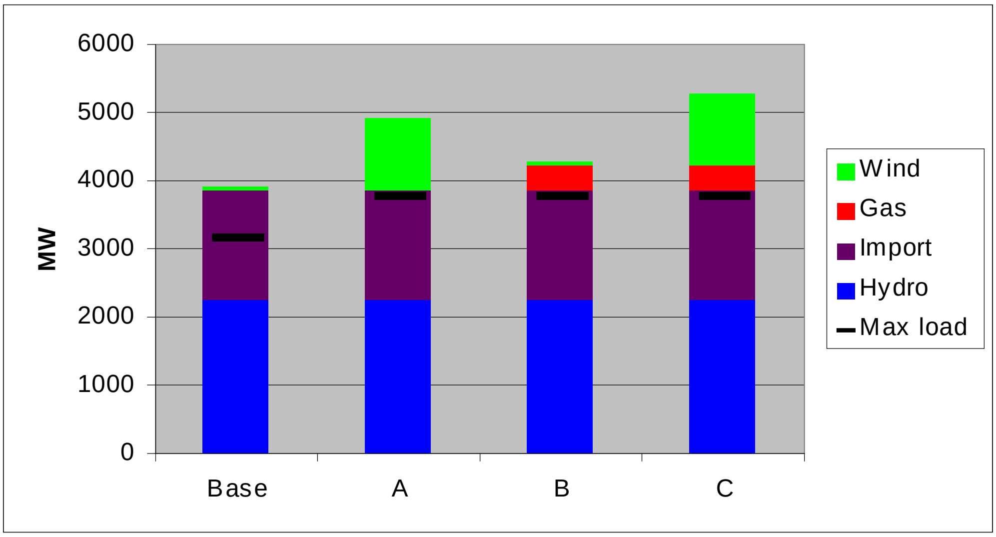
0,18 TWh wind / 62 MW (3 wind farms)

18 TWh annual load / 3180 MW max load
Increasing to 21 TWh / 3780 MW

Options
- A: 3 TWh wind / 1000 MW (3 wind farms)
- B: 3 TWh gas / 375 MW
- C: 3 TWh wind + 3 TWh gas

SINTEF   SINTEF Energy Research

Case study max load and generating capacity



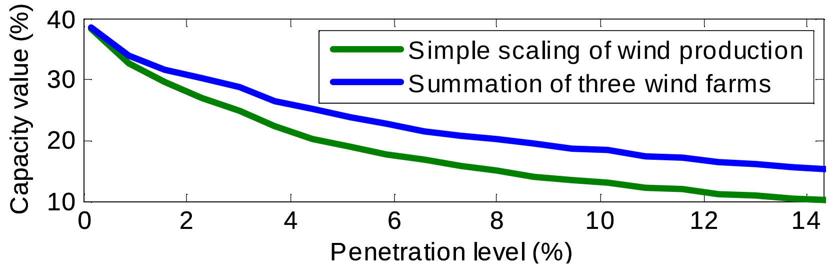
SINTEF   SINTEF Energy Research

Loss of load probability

	Base	A	B	C
LOLP (%)	0.11	7.2	1.43	0.35
Wind capacity value (%)	31.5	14.7	34.3	13.6
Gas capacity value (%)	-	-	95.2	94.7
Wind penetration (%)	1.0	15.2	0.9	15.2

Without new generation in case A, B and C the LOLP=26%

Wind capacity value



SINTEF   SINTEF Energy Research

Conclusion

- The impact of wind power on system adequacy has been studied for a real life regional hydro-based power system.
- Adding wind or gas generation contribute equally to the energy balance, both on a weekly and annual basis.
- Both wind and gas improves the power balance.
- The capacity value of gas is found to be about 95 % of rated, and the capacity value of wind about 30 % at low wind energy penetration and about 14 % at 15 % penetration.
- The smoothing effect due to geographical distribution of wind power has a significant impact on the wind capacity value at high penetration.
- Adding storage to wind is a promising technology for future high wind penetration systems enhancing wind controllability and value.

Best practices in grid integration of variable wind power: case studies from recent U.S. analyses and mitigation measures. *J. Charles Smith, UWIG, US*

European Wind Integration Study EWIS for a successful integration of wind power into European electricity grids. *Wilhelm Winter, EWIS, Belgium*

Transmission investment for wind generation. *Goran Strbac, DG&SEE, UK*

The All Island Renewable Grid Study. *Mark O'Malley, University College Dublin, IR*

Assessment of existing constraints and solutions for high wind penetration in power systems. *Ana Estanqueiro, INETI, Portugal*

Integration state-of-the-art in Germany. *Cornel Ensslin, ISET, Germany*

Operational costs induced by fluctuating wind power production in Germany and Scandinavia. *Peter Meibom, Risoe National Laboratory, Denmark*

100% wind energy: consequences on market and system - study on a fictitious Western Danish power system. *Antje Orths, Energinet.Dk, Denmark*

Integration state-of-the-art in Sweden. *Lennart Söder, KTH, Sweden*

Imbalance costs of wind power for a hydro power producer in Finland. *H.Holttinen, VTT, Finland*

Impact of large scale wind power on system adequacy. *John Olav Tande, SINTEF, Norway*

Tradewind - further developing Europe's power market for large scale integration of wind power. *Frans Van Hulle, EWEA, Belgium*

TradeWind: further developing Europe's power market for large scale integration of wind power

WHAT?

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

OBJECTIVE

Focus on how to facilitate wind power integration by studying:

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

TradeWind: further developing Europe's power market for large scale integration of wind power

DONE SO FAR

- EU wide dispersed WP capacity installed up to 2030 and regionally aggregated wind power production time series
- EU wide survey and analysis of power market mechanisms and how wind power is integrated in market
- Put models in place to simulate effect of wind on continental power flows and effects of market rules

TARGET and LINKAGE

- TEN-E, market parties (regulators, producers, TSO's, power traders), EU and national governments (e.g. TEN-E)
- Intention of co-operation and exchange with EWIS study

Further info: poster session and www.trade-wind.eu

IEA WIND Task 25: Design and operation of power systems with large amounts of wind power

- started in 2006
- duration 3 years
- www.ieawind.org

	Country	Participating institution
	Denmark	Risø National Laboratories (Peter Meibom) TSO Energinet.dk (Antje Orths)
	EWEA	European Wind Energy Association (Frans van Hulle)
	Finland	VTT Technical Research Centre of Finland (OA)
	Germany	ISET (Cornel Ensslin), TSOs E.ON (Lutz Hofmann) and RWE (Bernhard Ernst)
	Ireland	Research organisation to be confirmed TSO Eirgrid (Paul Smith)
	Norway	SINTEF (John Olav Tande), Statkraft (Espen Hagstrøm)
	Netherlands	we@sea, ECN (Jan Pierik)
	Portugal	INETI (Ana Estanquiero), UTL-IST (Rui Castro), TSO REN (João Ricardo), INESC-Porto (J. Pecas Lopes)
	Spain	University of Castilla La Mancha (Emilio Gomez)
	Sweden	KTH (Lennart Söder)
	UK	DG&SEE Centre for Distrib. Gener. & Sustainable Electrical Energy (Goran Strbac)
	USA	NREL (Brian Parsons), UWIG (Charles Smith)