DTU Wind Energy

DTU contributions to IEA Wind Annex 25 Phase 2

Department of Wind Energy Report 2012

Poul Sørensen, Nicolaos Cutululis, Peter Meibom

DTU Wind Energy E-0014 (EN)

October 2012

DTU Vindenergi
Institut for Vindenergi

Author (s): Poul Sørensen, Nicolaos Cutululis, Peter Meibom
Title: DTU contributions to IEA Wind Annex 25 Phase 2
Department: Department of Wind Energy

DTU Wind Energy E-0014 (EN)
October 2012

Summary (max 2000 characters):
The objective of Task 25 is to analyse and further develop the methodology to assess the im-pact of wind power on power systems. The Task has established an international forum for ex-change of knowledge and experiences related to power system operation with large amounts of wind power and has actively followed parallel activities with Transmission System Operators other R&D Task work. The participants have collected and shared information on the experience gained and the studies made up to and during the task. The case studies have addressed different aspects of power system operation and design, mainly: balancing, grid impacts and capacity credit of wind power.

In the meetings, all participants have made presentations of the wind integration issues in their country, results so far and on-going activities. In the latest meetings presentations have been grouped to different topics to better dwell into the details of modelling challenges. In addition, there has been some telephone/web meetings for the journal articles and Recommendations report. In the Task 25 meetings, updates from other international work are also given (EU/TPWIND and SET-Plan, IEEE, IPCC). TSO collaboration is important for Task 25 work. There has been TSO participation in all meetings, with the participants from Canada, Denmark and Italy in most meetings and some other countries sending TSO participants in fewer meet-ings

Contract no.:
64009-0100

Project no.:
64009-0100

Sponsor:
Danish Energy Agency

Pages: 50
Tables: 1
References: 1

Technical University of Denmark
Department of Wind Energy
Frederiksborgvej 399
Building 118
4000 Roskilde
Denmark
Telefon 21 36 27 66
posq@dtu.dk
www.vindenergi.dtu.dk

Preface

This report presents the results of DTUs participation in IEA Wind Task 25 – Phase 2. DTUs participation in Task 25 Phase 2 has been funded by the Danish Energy Agency program for development and demonstration of the Danish energy policy (EUDP-09-I journal nr. 64009-0100). From DTU, Peter Meibom has done a great work in Phase 1 and Phase 2 until he left DTU 31 October 2012. The undersigned has been less involved phase 2, but represents DTU in Phase 3 together with Nicolaos Cutululis.

Roskilde, October 2012

Poul Sørensen
Professor

Content

Summary

The objective of Task 25 is to analyse and further develop the methodology to assess the impact of wind power on power systems. The Task has established an international forum for exchange of knowledge and experiences related to power system operation with large amounts of wind power and has actively followed parallel activities with Transmission System Operators other R&D Task work. The participants have collected and shared information on the experience gained and the studies made up to and during the task. The case studies have addressed different aspects of power system operation and design, mainly: balancing, grid impacts and capacity credit of wind power.

In the meetings, all participants have made presentations of the wind integration issues in their country, results so far and on-going activities. In the latest meetings presentations have been grouped to different topics to better dwell into the details of modelling challenges. In addition, there has been some telephone/web meetings for the journal articles and Recommendations report. In the Task 25 meetings, updates from other international work are also given (EU/TPWIND and SET-Plan, IEEE, IPCC). TSO collaboration is important for Task 25 work. There has been TSO participation in all meetings, with the participants from Canada, Denmark and Italy in most meetings and some other countries sending TSO participants in fewer meetings

1. Introduction

An R&D Task titled “Design and Operation of Power Systems with Large Amounts of Wind Power” was formed in 2006 within the “IEA Implementing Agreement on the Co-operation in the Research, Development and Deployment of Wind Turbine Systems” (www.ieawind.org) as Task 25. The aim of the R&D task is to collect and share information on the experience gained and the studies made on power system impacts of wind power, and review methodologies, tools and data used.

The objective of Task 25 is to analyse and further develop the methodology to assess the impact of wind power on power systems. The Task has established an international forum for exchange of knowledge and experiences related to power system operation with large amounts of wind power and has actively followed parallel activities with Transmission System Operators other R&D Task work. The participants have collected and shared information on the experience gained and the studies made up to and during the task. The case studies have addressed different aspects of power system operation and design, mainly: balancing, grid impacts and capacity credit of wind power.

Since Task 25 was initiated in 2006 for a three years period, it has been extended twice, so at this stage, the work is in three phases:

- Phase 1 (2006 – 2008)
- Phase 2 (2009 – 2011)
- Phase 3 (2012 – 2014)

The Task is currently finalizing the final summary report of IEA WIND Task 25, Phase 2 (2009 – 2011) (Holttinen et.al.) which will include the contributions from DTU. The final version of the summary report is planned to be published by the end of October 2012. Thus, this report aims at presenting, in short, the main coordinates of the activities in the Phase II, with focus on the meetings and the presentations that were facilitated through the project. The summary report will be forwarded to EUDP once it is published.

Wind power in Denmark is expected to cover up to 50% of electricity consumption in 2020 according to the policy announced in 2011. The activities in IEA Wind Annex 25 have provided access to international knowledge exchange and corporation about power systems with large shares of wind power in the Annex will therefore contribute to achieving the large share of wind power in the Danish power system in a secure and economically efficient way.

2. Participants

The work plan and administration of Task 25 is managed by VTT Technical Research Centre of Finland that has designated Dr. Hannele Holttinen to carry out the work

Task 25 has participants from research institutes, transmission system operators, electric utilities and other stage holders.With the objective to analyse and further develop the methodology to assess the impact of wind power on power systems, it has been particularly valuable to have participation from 6 Transmission system Operators (TSOs from Denmark, Norway, Ireland, Germany, Portugal and Spain) from countries with large scale wind power in the power systems.

The following countries and institutes have participated in phase 2 of Task 25:

Country	Organisation
Canada	Hydro Quebec
Denmark	Energinet.dk Technical University of Denmark - Risø DTU
Europe	EWEA European Wind Energy Association
Finland	VTT Technical Research Centre of Finland
Germany	Amprion Fraunhofer IWES
Ireland	Eirgrid SEI UCD ECAR
Norway	Statnett SINTEF
Netherlands	ECN TUDelft
Portugal	REN INESC-Porto LNEG IST
Spain	REE University Castilla La Mancha
Sweden	KTH
UK	Centre for Distributed Generation & Sustainable Electrical Energy
USA	USA: NREL; UWIG.

3. Meetings in Phase 2

The international forum for exchange of knowledge and experiences has been established through the meetings organised so far. The second phase of the Task 25 activities included 6 meetings, given in the following list. The numbering of the meetings is including the phase I activities, hence it starts with the 7th overall Task 25 meeting.

- 7th R&D meeting in London, UK, March 2009, hosted by DG&SEE (Imperial College). 22 people from 11 countries +EWEA were present.
- 8th R&D meeting at ECN, the Netherlands, October 2009, hosted by ECN. 22 people from 12 countries + EWEA were present
- 9th R&D meeting in Toledo, Spain, March 2010, hosted by University Castilla la Mancha together with the Regional Energy Agency. 24 people from 12 countries + EWEA were present
- 10th &D meeting in Montreal, Canada, October 2010, hosted by Hydro Quebec. 28 people from 13 countries + EWEA were present
- 11th R&D meeting in Stockholm, Sweden, April, 2011, hosted by KTH, 20 people from 11 countries + EWEA were present
- 12th R&D meeting in Lisbon, Portugal, September, 2011, hosted by LNEG, 21 people from 13 countries + EWEA were present

In the meetings, all participants have made presentations of the wind integration issues in their country, results so far and on-going activities. In the latest meetings presentations have been grouped to different topics to better dwell into the details of modeling challenges. In addition, there has been some telephone/web meetings for the journal articles and Recommendations report. In the Task 25 meetings, updates from other international work have also been given (EU/TPWIND and SET-Plan, IEEE, IPCC).

4. DTU contributions to phase 2

The presentations done fully or partially by DTU in internal Task 25 Phase 2 meetings are copied in Appendix A. It consists of the following presentations:

- Peter Meibom. Forecasts in Unit Commitment Models (October 2009). Petten, Netherlands
- Poul Sørensen. IEC 61400-27 Electrical simulation models for wind power generation (October 2009). Petten, Netherlands
- Peter Meibom. Recent activities and planned work (March 2009). London, United Kingdom
- Juha Kiviluoma (VTT) and Peter Meibom (DTU). Results from comparing deterministic, stochastic, MIP and LP WILMAR runs for systems with wind power and electric vehicles (March 2010). Toledo, Spain
- Peter Meibom. Advanced Unit Commitment in Eastern Interconnector (April 2011). Stockholm, Sweden

IEA Task 25 Phase 2 has published the following presentations / papers with participation form Denmark:

- Kiviluoma, J., Meibom, P., Tuohy, A., Troy, N., Milligan, M., Lange, B., Gibescu. M., O'Malley, M., Short term energy balance with increasing levels of wind energy, IEEE Transactions of Sustainable Energy, Vol. 3, Issue 4, pp. 769-776, 2012, DOI: 10.1109/TSTE.2012.2209210
- Holttinen, H., Meibom, P., Orth, A., Lange, B., O'Malley, M., Tande, J.O., Estanqueiro, A., Gomez, E., Söder, L., Strbac, G., Smith, J.C., van Hulle, F., Impacts of large amounts of wind power on design and operation of power systems, results of IEA collaboration, Wind Energy, Vol. 14, pp. 179-192, 2011, epublished, DOI: 10.1002/we.410.
- Invited presentation of Task 25 in AnemosPlus (EU project) workshop, Paris 29th June, 2011 (H.Holttinen)
- Kiviluoma J, O'Malley M, Tuohy A, Meibom P, Milligan M, Lange B, Holttinen H, Gibescu M, "Impact of Wind Power on the Unit Commitment, Operating Reserves and Market Design", in Proc. of IEEE Power and Energy Society General Meeting 24 – 28 July 2011, Detroit, USA (presented by P.Meibom, Risö-DTU)
- EWEA2011 conference: Task 25 grid integration session in IEAWIND side event 16th March, 2011 (three presentations from OA, Peter Meibom Risö-DTU and J Charles Smith, UWIG)
- Invited presentation in Exchange of balancing services between the Nordic and the Central European synchronous systems, International workshop 26-27 January 2011, Oslo Gardemoen, Norway
- Invited presentation in EWEAs GRIDS2010 conference on 24th November, 2010.
- Session on European experiences in UWIG seminar 15th Oct 2010, Quebec
- Presentation in IEA ECES (storage implementing agreement) workshop 14-15th July 2010, Germany (F.Schlögl)
- Presentations of Task 25 for ENTSO-E Renewable energy working group, May 2010 (H.Holttinen, M.O'Malley)
- Presentation of Task 25 work for IEA electricity coordination group workshop meeting Apr 2010, Paris (H.Holttinen)
- Paper and presentation, Bremen wind integration workshop Oct 2009 (H.Holttinen), Task 25 session with presentations from US, Canada, Finland/Denmark and Ireland
- Kassel Energy Symposium Sep 2009 (H.Holttinen)
- IEA Secretariat Electricity Grid Coordination Meeting Feb 2009 (L.Söder)
- EU project SOLID-Der workshop Feb 2009 (J.Kiviluoma)
- IEA Secretariat IREG2 project kick-off meeting Feb 2009 (H.Holttinen)
- European Wind Energy Conference EWEC'2009 March 2009 (H.Holttinen)
- Paper and presentation Wind Integration workshop in Madrid (H.Holttinen) and AWEA Windpower 2008 in Houston (presented by B.Parsons)

5. Future work (Phase 3)

The relevance of the activities in Task 25 was recognized and an extension was approved by the IEA WIND Executive Committee in 2011. Phase III is covering the period 2012 – 2014. The Danish participation is supported through an EUDP financed project: journalnr 64012-0135. The overall objective for Task 25 during the next period remains the same as when the Task started: to provide information to facilitate the highest economically feasible wind energy penetration within electricity power systems worldwide. Task 25 supports this goal by analysing and further developing the methodology to assess the impact of wind power on power systems and by producing information on the range of impacts and best practices to assess the impacts. Expected results are:

- Enhanced international collaboration and coordination in the field of wind integration
- Database for large scale wind power production time series

- Collaborative journal articles summarising and further analysing the work in national case studies
- Updated library of wind integration case studies
- Updated Recommended Practices report

DTU will contribute to these results by participation in meetings and contributions to the reports written in the annex. Expected contributions from DTU are:

- Scenarios for wind power development
- Synthetic wind power time series.
- Methodology: Intra hour balancing and reserve requirements. Use of joint Energinet.dk / DTU tool Simba for simulation of balancing in the Danish power system.
- Wind power contribution to ancillary services - results from EU Reservices project
- Dynamic wind power models for stability studies - results from development of new standard IEC 61400-27

References

Holttinen, Hannele (2012): Design and operation of power systems with large amounts of wind power. Final summary report, IEA WIND Task 25, Phase two 2009–2011. Draft 2012-04-24, Publisher VTT Technical Research Centre of Finland, Vuorimiehentie 5, P.O. Box 1000, FI-02044 VTT, Finland.

Appendix A DTU presentations

This appendix provides the slides from the following presentations fully or partly done by DTU at a biannual task force 25 – Phase 2 meeting:

Including wind power forecasts in unit commitment models

Peter Meibom, Risø DTU, October 12th 2009, Petten, The Netherlands

Content

- Generate wind power forecasts
- Wind power in unit commitment (UC) and economic dispatch (ED) models:
  - Starting point
  - Rolling planning
  - Using expected wind power (deterministic with forecast error)
  - Additional demand for reserves
  - Stochastic programming (multiple forecasts)

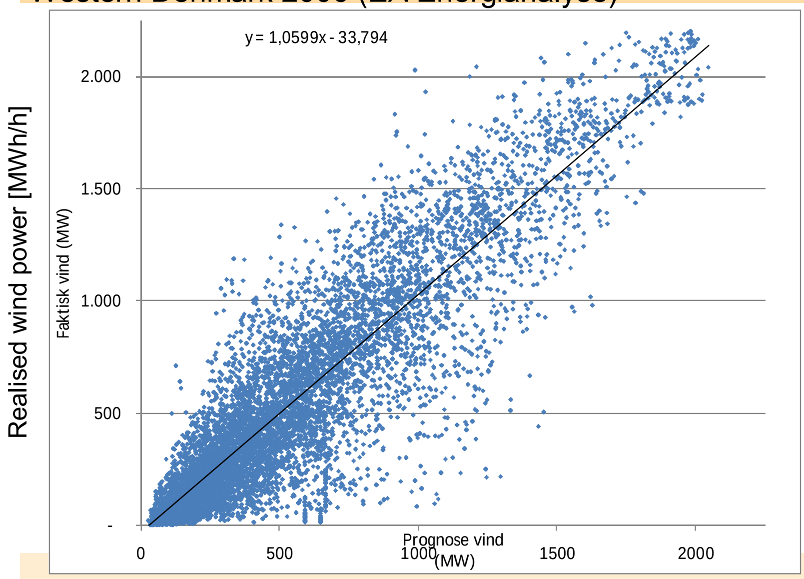
2

Generate wind power forecasts

- Until now: simulated wind power forecasts
- Ongoing work: using real wind power forecasts in UC tools (e.g. Anemos Plus)
- Replace assumption about wind power forecasts errors being normally distributed with
  - wind speed forecast errors being normally distributed
  - due to shape of power curve of wind turbines
- Wind power forecast error dependant on forecast horizon?
  - Weak dependence for forecast horizons above 6 hours
  - So we have to create liquid intra-day markets with gate closure times below 6 hours

3

Western Denmark 2006 (EA Energianalyse)

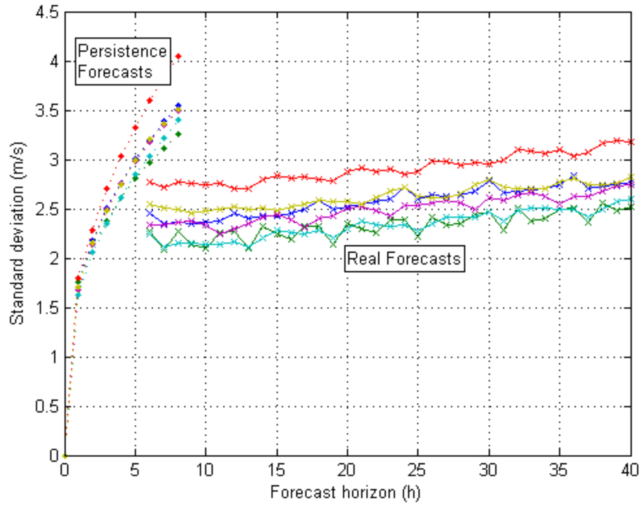


4

DTU

RISØ

Standard deviations of wind speed forecast errors for 6 Irish locations



5

DTU

RISØ

UC models

- Mixed integer linear programming model
- Objective function: minimisation of operational costs
- Binary decision variable: online status of unit
- Positive decision variable: power generation of unit
- System wide restrictions:
  - E.g. supply/demand balances: power, reserves
- Unit restrictions
  - E.g. capacity restrictions, minimum up and down time, start-up times
- For large power systems often solved by relaxing the binary requirement i.e. 0 ≤ online status ≤ 1 giving linear programming problem

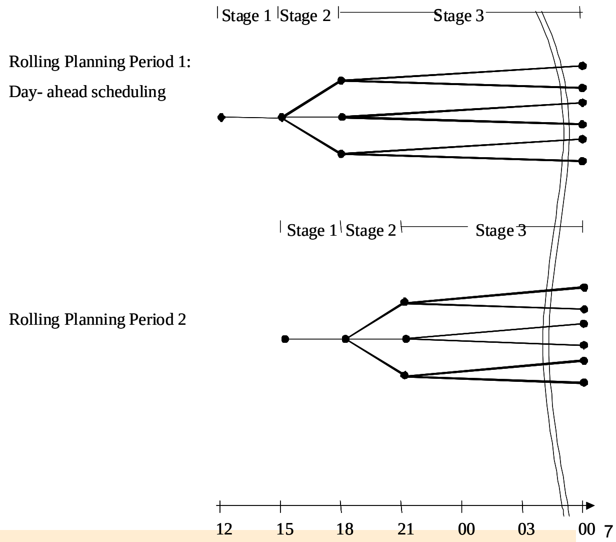
6

DTU

RISØ

Adding wind power forecasts to UC models

- Rolling planning due to updated forecasts



7

DTU

RISØ

Adding wind power forecasts to UC models

- Using one forecast (expected wind power)
  - Deterministic with forecast error
  - Only one UC commitment schedule
  - No up/down regulation required within one planning loop
- Add increased demand for reserves due to wind power forecast errors:
  - Allocation of production capacity from spinning units or fast starting off line units to cover demand for reserves

8

DTU RISØ

Calculation of demand for reserves

- Calculation of increased reserve demand should be done by combining all uncertainty i.e. forecast errors of wind power production and load and forced outages of units and lines
- Demand for reserves should be calculated relatively to expected wind power production and load for a given forecast horizon

9

DTU RISØ

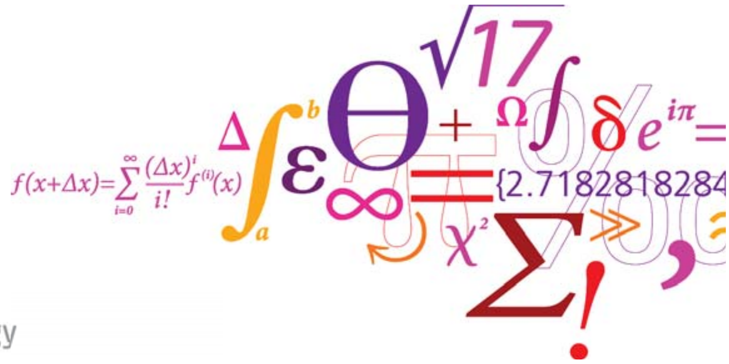
Adding wind power forecasts to UC models

- Stochastic programming handling several wind power forecasts (Wilmar):
  - Several tentative UC plans for future time steps
  - Up/down regulation within one planning loop
  - More capacity started up to cover several future UC plans
  - Better than deterministic with forecast error in model studies [Tuhoy et. al., IEEE Trans. Power Systems, 2009]:
    - Operational costs differences small (below 1%)
    - Large differences in usage of mid merit and peak load power plants
  - But deterministic with forecast error maybe the way UC actually takes place today
  - Very demanding with regard to calculation times, generation of stochastic input and data

10

IEC 61400-27
Electrical simulation models for wind power generation

Poul Sørensen
Risø DTU
Roskilde
Denmark



Risø DTU
National Laboratory for Sustainable Energy

Outline of this presentation

1. Scope
2. Votes and comments from national committees
3. Members
4. Time schedule
5. Kickoff meeting 6-7 October

Scope of IEC 61400-27

- Define standard dynamic simulation model for wind power
- Application:
  - Power system and grid stability analysis
  - Applicable for dynamic simulations of
    - Short circuits (fault ride through)
    - Loss of generation or load
    - System separation
- 2 parts
  1. Wind turbines
  2. Wind farms

Scope of IEC 61400-27 – part 1

- Wind turbine modelling must define:
  - Generic dynamic models for topologies / concepts on market
  - Methodology to create models for new concepts
  - Model parameters
  - Models refer to wind turbine connection terminal
  - Independence on simulation tool
    - To outmost degree
    - With clear definition of interface to simulation tool
- Validation
  - Shall include tests according to IEC 61400-21
    - Response to voltage dips
    - Set point requests

Scope of IEC 61400-27 – part 2

- Wind turbine modelling must define:
  - Generic dynamic models for topologies / concepts on market
    - Auxiliary equipment
    - Wind farm control
  - Methodology to create models for new concepts
  - Models refer to wind farm point of common coupling
  - Independence on simulation tool
    - To outmost degree
    - With clear definition of interface to simulation tool

- Validation

IEC TC88 NWIP – Votes

Country	Status	Received	Approving	CD	CDV	Participation	Comments
Australia	O	2009-03-12	Y	Y	N	N	-
Belgium	O	2009-02-13	A	N	N	N	-
Brazil	O	2009-03-13	A	N	N	N	-
Canada	P	2009-03-05	A	N	N	N	-
China	P	2009-03-12	A	N	N	N	-
Denmark	P	2009-03-12	Y	Y	N	N	-
Finland	P	2009-03-13	Y	Y	N	Y	-
France	P	2009-03-04	Y	Y	N	Y	Y
Germany	P	2009-03-06	Y	N	N	Y	Y
India	P	2009-03-09	Y	Y	N	N	-
Italy	P	2009-03-10	Y	Y	N	N	-
Korea (Rep. of)	P	2009-03-13	Y	N	N	N	-
Netherlands	P	2009-03-09	Y	N	Y	N	-
Portugal	P	2009-03-13	Y	Y	N	N	-
Romania	O	2009-03-04	Y	Y	N	N	-
Russian Fed.	O	2009-03-13	Y	N	N	N	-
Slovenia	O	2008-12-16	Y	N	Y	N	-
Spain	P	2009-03-13	Y	Y	N	N	-
Sweden	P	2009-03-13	Y	N	N	Y	-
U.S.A.	P	2009-03-13	Y	Y	N	N	Y
United Kingdom	P	2009-03-12	Y	Y	N	Y	-

	Approval Criteria	Result
Number of P-members: 19		
P-members voting: 13		
P-members approving: 13 = 100 %	**> 50%**	**APPROVED**
P-members ready to participate in the development and approving addition of the proposal: 5	**>=4 (if <=16) >=5 (if >= 17)**	**APPROVED**

Annex

Date	Document	Project Nr.
2009-03-02	**88/334/NP**	IEC PNW 88-334 Ed.1.0

National Committee	Line number	Clause/ Subclause	Paragraph Figure/ Table	Type of comment (General/ Technical/Editorial)	COMMENTS	Proposed change	OBSERVATIONS OF THE SECRETARIAT on each comment submitted
DE01				G	We support the work on the proposed IEC Standard. We nominate the following experts. Mr. Jens Fortmann REpower Systems AG Hollesenstr. 15 D – 24768 Rendsburg Phone: +49 (0)4331 13 139 – 418 e-mail: j.fortmann@repower.de Mr. Frank Martin Germanischer Lloyd Industrial Services GmbH Competence Centre Renewables Certification Dept.:Machinery Components and Safety Steinhoeft 9 D – 20459 Hamburg Phone: +49 (0)40 – 361 49 – 7187 Fax: +49 (0)40 – 361 49 – 1720 e-mail: frank.martin@gl-group.com Mr. Martin Schellschmidt Enercon GmbH Dept. R & D Electrical Engineering Dreekamp 5 D – 26605 Aurich Phone: +49 (0)4941 – 927 – 448 Fax +49 (0)4941 – 927 - 309 martin.schellschmidt@enercon.de		Nomination of the three experts by the German NC is very welcome.
DE02					We support the scope of the proposed IEC Standard.		Noted.

National Committee	Line number	Clause/ Subclause	Paragraph Figure/ Table	Type of comment (General/ Technical/Editorial)	COMMENTS	Proposed change	OBSERVATIONS OF THE SECRETARIAT on each comment submitted
DE03					The current version of the proposed IEC-Standard should not be published as CD or CDV. At the present stage, it is merely a first summary of work topics.		It is noted that under the heading of 'Preparatory work' in 88/334/NP the statement that 'An outline is attached' is checked. In the attachment under the title 'Outline', hoever, as opposed to the set of headings Introduction Aim of the new standard Purpose of the new standard Outline for the new standard Stakeholders and participants Time schedule and working procedures Summary Description is provided only under the headings Introduction Scope Aim of the new standard Stakeholders and participants Supporting requirements Proposed - Time Schedule Summary. Consistent with the spirit of this comment, therefore, the initial task of the project team shall be focussed on clear broader definition of the outline to establish consensus providing sound basis for their work.
FR					The French National Committee casts a positive vote on the above new work item proposal and proposes the following expert: Jérôme DUVAL jerome-c.duval@edf.fr EDF R&D 1 avenue du Général de Gaulle 92 140 CLAMART – FR		Nomination of an expert by the French NC is very welcome.

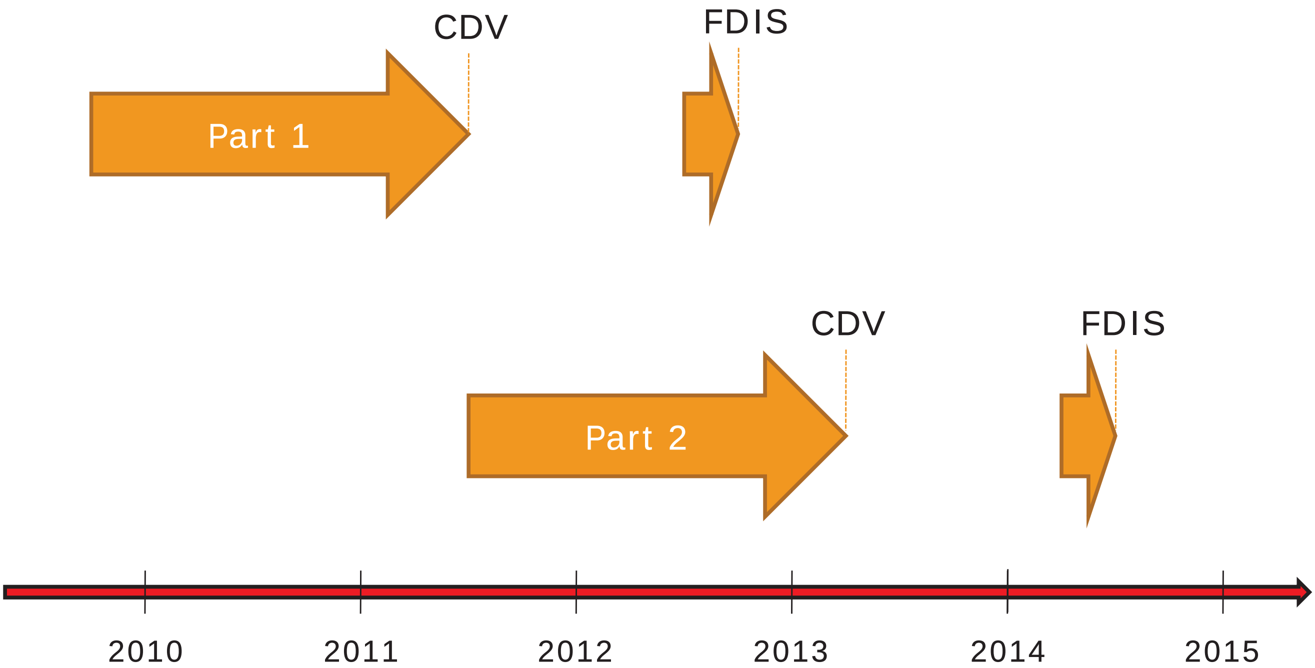
National Committee	Line number	Clause/ Subclause	Paragraph Figure/ Table	Type of comment (General/ Technical/Editorial)	COMMENTS	Proposed change	OBSERVATIONS OF THE SECRETARIAT on each comment submitted
US				G	The US strongly supports the establishment of an IEC project to define standard models for grid connected wind turbines and wind power plants. Much work has already been done within the IEEE, WECC and other groups. This new IEC work should be coordinated with this earlier work to avoid duplication of effort.		Noted. Nomination of an expert by the US NC would be most welcome.

IEC TC88 WG27 members

- Michael Ebnicher, Bachmann electronic GmbH (AT)
- Frank Martin, Germanischer Lloyd Industrial Services GmbH (DE)
- Jens Fortmann, REpower Systems AG (DE)
- Frank Fischer, PowerWind GmbH (DE)
- Jeferson Marques, Enercon (to replace Martin Schellschmidt, DE)
- Bo Hesselbæk, Vestas Wind Systems A/S (DK)
- Vladislav Akhmatov, Siemens Wind Power (to be appointed, DK)
- Björn Andresen, Siemens Wind Power (DK)
- Nan Qin, Energinet.dk (to replace Knud Johansen, DK)
- Poul Sørensen, Risø DTU (DK)
- Montserrat Mata, ECOTÈCMOA / ALSTOM (ES)
- Emilio Gómez Lázaro, UCLM Research Institute (ES)
- Alberto Molina Martín, ENERGY TO QUALITY S.L. (ES)
- Jouko Niranen, ABB (FI)
- Slavomir Seman, ABB (FI)
- Jerome Duval, EDF R&D (FR)
- Graeme Bathurst, TNEI Services Ltd (GB)
- Edwin Wiggelinkhuizen, ECN Wind Energy (NL)
- Jarle Eek, SINTEF Energiforskning (NO)
- Larisa Vladimirovna Varigina, JSC “NIIES” JSC “RusHydro” (RU)
- Åke Larsson, Vattenfall (SE)
- Pouyan Pourbeik, Electric Power Research Institute (US)
- Abraham Ellis, Sandia National Laboratories (US)
- Nicholas Miller, GE Energy (US)
- Eduard Muljadi, National Renewable Energy Laboratory (US)
- Yuriy Kazachkov, Siemens PTI (US)
- Robert Zavadil, EnerNex Corporation (US)

10 **Risø DTU, Technical University of Denmark** IEA Annex 25 - Petten, Holland 12 Oct 2009

Tentative time schedule – WG27



Presentations / discussions of kick-off meeting

- Scope, time schedule, drafting of standard outline / Poul Sørensen
- US: North America Dynamic Wind Generator Modeling Update - Based on work performed by the Western Electricity Coordinating Council (WECC) Wind Generator Modeling Group and the IEEE Dynamic Performance of Wind Power Generation Working Group/ Pouyan Pourbeik
- GB contributions to IEC TC88 WG27 / Graeme Bathurst
- NO: Generator Technology (PMSG/DFIG) Influence on Low Frequency Electromechanical Oscillations / Jarle Eek
- FI: Standardized WT model – Model Specifications, Validation, Challenges / Slavomir Seman
- DK: Experience with wind turbine modeling / Vladislav Akhmatov
- DK: Risø DTU modelling activities / Poul Sørensen
- FR: EDF R&D background concerning wind generation/ Jerome Duval
- AT: Bachmann electronic in Wind / Michael Ebnicher
- ES: Spanish procedure for verification, validation and certification on response of wind farms to voltage dips / Montserrat Mata
- DE: Key Issues of the German Guideline on mode validation (TR4) / Jens Fortmann

Discussion points

- Models
  - Simplicity versus accuracy
  - Fault ride through capability included (or simply dynamic response assuming FRT)
  - Linearisation of Cp curves
  - RMS / EMT
  - Symmetric / asymmetric faults
  - Use existing standard models for auxiliary equipment (SVCs etc)
  - Simplified models (current or voltage sources)

- Validation
  - Transient and stationary intervals
  - Validation of plant only (voltage input) or of plant in whole system (system model)

Draft Outline of IEC 61400-27

- FOREWORD
- INTRODUCTION – (gen models, FRT through factory tests)
- 1 Scope
- 2 Normative references
- 3 Terms and definitions
- 4 Symbols and units
- 5 Abbreviated terms
- 6 Purpose and limits of application
- 7 Models
  - X known types
  - New types
- 8 Validation
  - Purpose of validation
  - Voltage dip response
  - Control setpoint

Focus document

- First priority of WG27 is to perpare Focus document specifying in more details:
  - Applicability and limits of models and validation procedures
  - Requirements to models and validation procedures
  - Document should focus work of TC88 WG27, and will be used for discussion with
    - National committees
    - Individual TSOs
    - ENTSO-E

15 **Risø DTU, Technical University of Denmark** IEA Annex 25 - Petten, Holland 12 Oct 2009

Recent activities and planned work 2009-2011

Peter Meibom, Risø DTU, March 2 2009, London

Content

- Recent results
  - 100% renewable energy system in 2060 in North Europe – role of large-scale (hydrogen) storage
  - Finland in 2025: nuclear versus wind power
  - Importance of intra-day rescheduling of power exchange between countries and unit commitment of power plants (Tradewind)
- Other wind power integration activities in Denmark
  - Energinet.dk: 50% wind power in Denmark in 2025
  - Electric boilers and heat pumps
  - Electric vehicles:
    - Project better place
    - Edison
- Planned activities at Risø DTU 2009-2011

2

DTU

RISØ

Role of large-scale storage

- Analysis done with Balmorel (www.balmorel.dk) : linear optimisation model generating investments
- Denmark, Germany, Finland, Norway, Sweden
- 100% renewable energy sources based energy system in 2060:
  - Biomass: only resources within the countries
  - Wind power
  - Solar heating and photo voltaics in Germany
- Investment possibilities:
  - Wind power on-shore and off-shore
  - Biomass CHP plant, hydrogen CHP plant (CC or fuel cell)
  - Electric boilers, heat pumps, heat storage
  - Hydrogen production using electrolysis or directly from biomass
  - Hydrogen storage
- Large energy savings assumed implemented in 2060

3

DTU

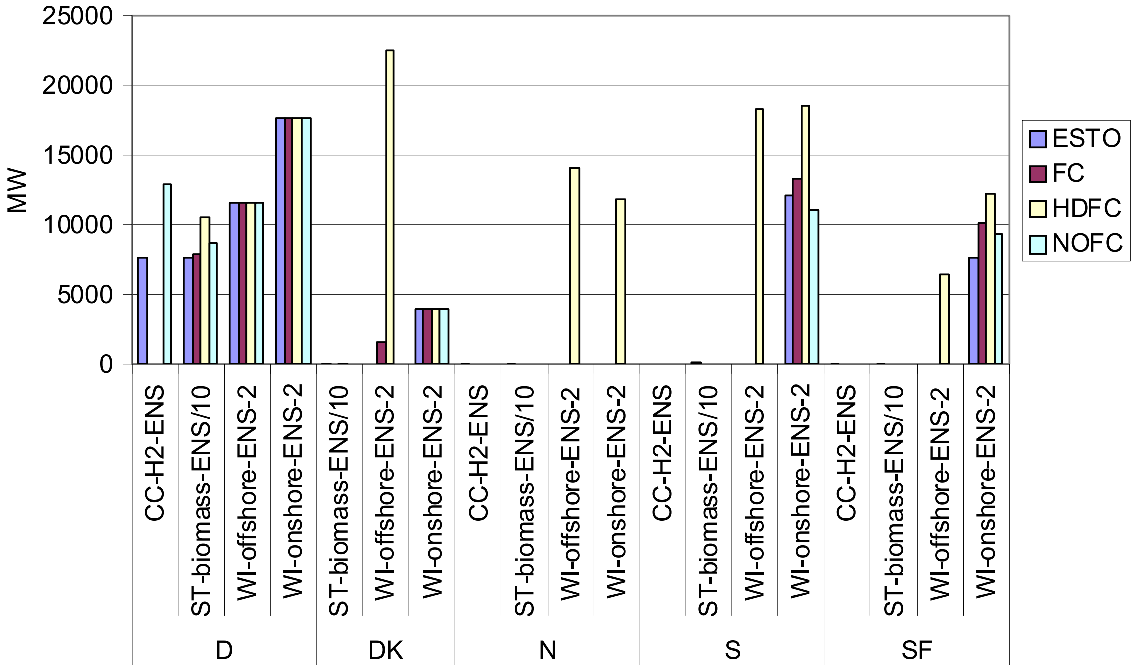
RISØ

Role of large-scale storage

- 6-hourly time step: reanalysis data for wind power
- Transport fuels for passenger cars either hydrogen or electricity
- **FC:** fuel cell technologies are successfully developed leading to introduction of electrolysis based on fuel cells, fuel cell power plants and fuel cell cars.
- **NOFC:** fuel cell technologies are not coming into the market place in larger quantities. Hence combined cycle power plants using hydrogen are replacing fuel cell power plants, alcaic electrolysis are replacing fuel cell electrolysis, and electric cars are used instead of fuel cell cars.
- **ESTO:** Same as NOFC except that the possibility for the electric cars of providing electricity storage to the power system is taken into account.
- **HDFC:** Same as FC except that the electricity and heat demands are increased 100% in order to test if the renewable energy sources are sufficient to cover a case with less energy savings implemented.

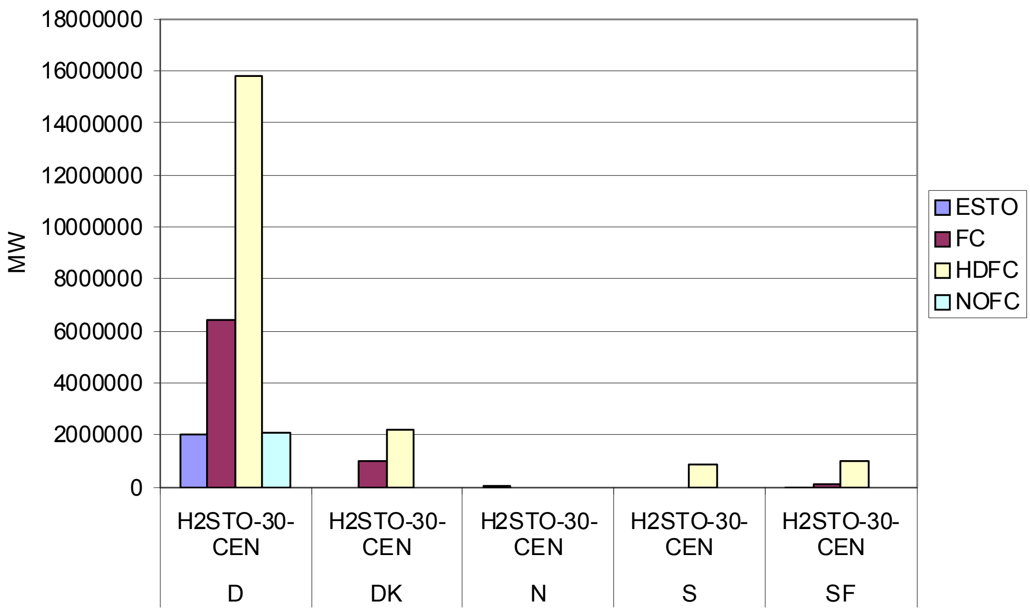
4

Investments in electricity generation equipment



5

Investments in hydrogen storage capacity



6

DTU

RISØ

Role of large-scale storage

- Investment in hydrogen storage capacity corresponded to 1.2% of annual wind power production in the scenarios without a hydrogen demand from the transport sector, and approximately 4% in the scenarios with a hydrogen demand from the transport sector
- Even the scenarios without a demand for hydrogen from the transport sector saw investments in hydrogen storage due to the need for flexibility provided by the ability to store hydrogen.
- The storage capacities of the electricity storages provided by plug-in hybrid electric vehicles were too small to make hydrogen storage superfluous.

7

DTU

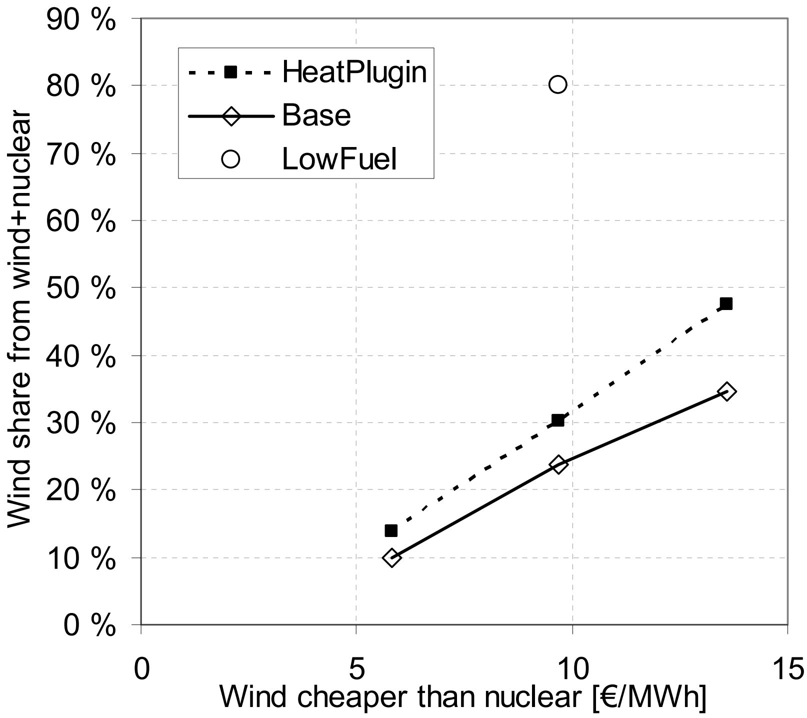
RISØ

Nuclear versus wind power

- Kivilouma & Meibom, Influence of wind power, plug-in electric vehicles, and heat storages on power system investments, submitted to Energy
- Balmorel analysis of Finland in 2035
- Hourly time resolution using 26 selected weeks to describe a year
- Base case without heat measures and plug-ins
- Heat measures: electric boilers, heat pumps and heat storages
- Plug-ins: charging and discharging of electric vehicles included in optimisation

8

Nuclear versus wind power



9

Importance of intra-day rescheduling (Tradewind)

- Wilmar calculation covering 25 European countries
- Comparison operational costs in 4 model runs:
  - **AllDay:** Unit commitment for slow units and power exchange over borders determined day-ahead (12-36 hours ahead) and not rescheduled intra-day. The dispatch (production levels) of the committed units can be changed intra-day subject to the minimum and maximum operation levels.
  - **ExDay:** Like AllDay except for unit commitment for slow units now being rescheduled intra-day. Cross-border exchange is still allowed day-ahead only.
  - **AllInt:** Like ExDay but power exchange allowed to be rescheduled intra-day.
  - **AllIntExRes:** Like AllInt but exchange of replacement reserves across borders allowed
- 2020 and 2030 scenarios for demand, wind power, fuel prices
- Wind share of consumption: 2020: 11%, 2030: 13%

10

DTU RISØ

Importance of intra-day rescheduling (Tradewind)

- Allowing for intra-day unit commitment is crucial:
  - 5% increase in total system costs when comparing *AllDay* and *ExDay* for both 2020 and 2030.
  - Extreme scenarios, because in reality some rescheduling will always take place.
  - 5% difference in system costs between *AllDay* and *ExDay* is very dependant on the assumed value of VOLL
- Value of intraday power exchange is 1% of total system costs being respectively 712 MEuro and 1420 MEuro for *AllInt2020* and *AllInt2030* compared to *ExDay2020* and *ExDay2030*.
- Only small costs savings of 40 MEuro for both 2020 and 2030 are associated with allowing exchange of replacement reserves across borders
  - No investment cost savings included

11

DTU RISØ

Wind power integration activities in Denmark (examples)

- 50% wind power (of consumption) in DK in 2025
  - According to recent energy agreements in Danish parliament
  - Wind power expansion mainly off-shore
  - Energinet.dk will analyse this challenge during the next years
- EDISON
  - Newly started research project involving Danish Energy association, DTU, Dong, IBM, Siemens
  - Development of power and information infrastructure for electric vehicles in DK
  - Development of architecture and algorithms for information handling and charging
  - Demonstration: Risø DTU – SYSLAB, Dong, Bornholm

12

Wind power integration activities in Denmark (examples)

- Project Better place:
  - DONG to invest 94 MEuros
  - 2009-2010: testing prototypes, building charging infrastructure
  - 2011: mass-produced electric vehicles for sale
- Day-ahead power market in Nordel:
  - Introduction of negative power market prices from October 2009
- Investment in electric boilers and maybe heat pumps by district heating companies in DK

13

Planned activities at Risø DTU 2009-2011

- Estimation of demand for minute reserves as a function of installed wind power capacity (SUPWIND)
- Demonstration of Wilmar Planning tool for day-to-day operation of power systems with high wind power penetration:
  - Ireland as case study in Anemos Plus
  - Denmark as case study in SUPWIND
- Influence of plug-in electric and hybrid electric vehicles for wind power integration:
  - Phd project and Danish research project (title: Power for road transport, flexible power systems and wind power). The influences on both day-to-day operation and on investments are analysed.
- The long-term development of power systems with high wind power penetration are analysed with optimisation models generating investments.

14

Planned activities at Risø DTU 2009-2011

- Simulation of wind power time series, particularly relevant for large scale offshore locations with geographical concentration of the wind power
- Frequency control of synchronous power systems with large scale wind power integration

15

Business from technology

Results from comparing deterministic, stochastic, MIP and LP WILMAR runs for systems with wind power and electric vehicles

IEA Wind Task 25 meeting, Toledo 16-17th March 2010

Juha Kiviluoma, VTT Technical Research Centre of Finland
Peter Meibom, Risø DTU

PLUG-IN ELECTRIC VEHICLES (EVs) AND WIND POWER INTEGRATION

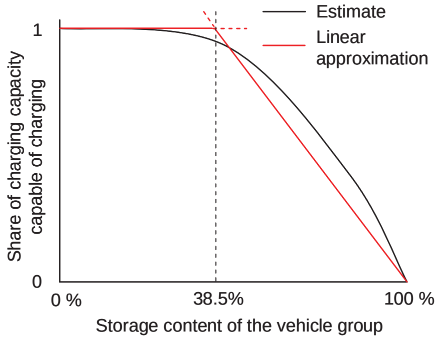
- Model runs with Wilmar and Balmorel
  - Investment decisions and costs from Balmorel
  - Operational costs from Wilmar
  - Both have EVs included (Wilmar more detailed)
  - Example case: Finland 2035
- Dumb charging EVs have similar effects as wind: net load variability increases
- Smart EVs can decrease costs of wind power integration

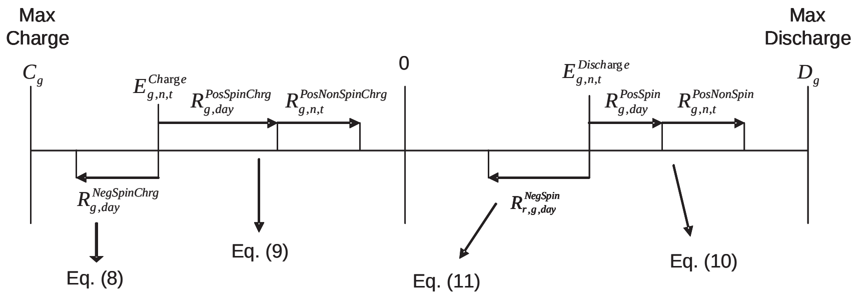
- Article just submitted

VTT TECHNICAL RESEARCH CENTRE OF FINLAND 16/03/2010 2

HOW TO MODEL EVs IN AN UC MODEL

- Time series for vehicles arriving and leaving the grid
  - Based on extensive travel survey data
  - Online storage, charging, and discharging capacities
  - kWh consumed before arriving
- Common storage pool for each vehicle type
  - When vehicle leaves it takes full battery kWh from the pool
  - When it arrives it releases what's left
- Charging/discharging optimised both day-ahead and intra-day
- Restrictions
  - Enough storage content to provide committed reserves





NEW INVESTMENTS IN DIFFERENT SCENARIOS (Balmorel)

Power Plant Type	MW of Electiricty No EVs	Dumb	Smart
NatGas comb. cycle cond.	363	467	17
NatGas comb. cycle CHP	3	0	0
NatGas open cycle cond.	2861	2307	2518
Nuclear	5312	5943	5311
Wind	4705	4458	6115
Forest residue CHP	1203	1203	1196
Wood waste CHP	76	55	72

STOCHASTIC/DETERMINISTIC AND MIP/LP COMPARISON

Annual system cost (M€) in different modes

Increase in annual system costs with 'dumb' or 'smart' Evs

Consumption has increased by 3.48%

	No EVs	Dumb	Smart
Stoch MIP	4745	5.49 %	1.24 %
Stoch LP	4739	5.49 %	1.32 %
DetFor MIP	4751	5.46 %	1.29 %
DetFor LP	4746	5.45 %	1.34 %

Smart EVs decrease start-ups

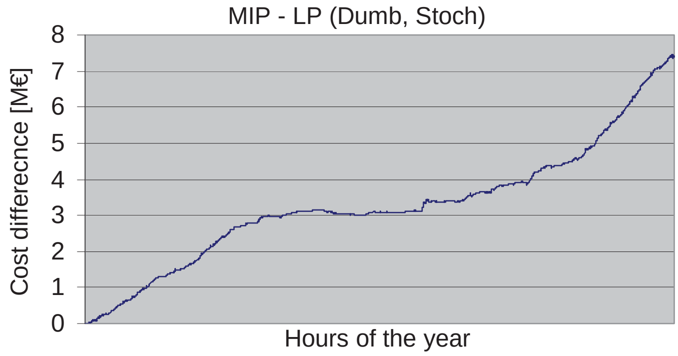
Stochastic information adds value to the EV optimisation

Very small differences
–
Lot of small units in the system

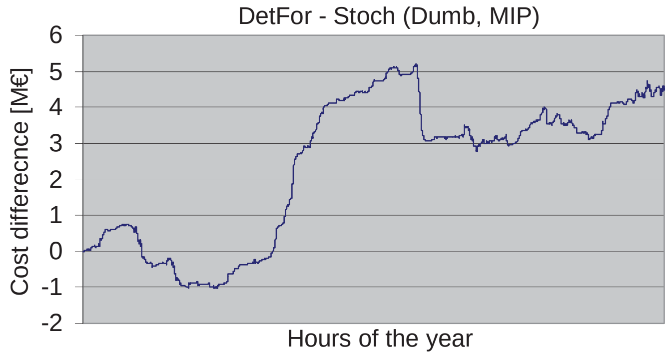
VTT TECHNICAL RESEARCH CENTRE OF FINLAND 16/03/2010 5

INSIGHTS FROM THE DATA

- MIP gets more expensive than LP slowly over time
  - → Higher start-up costs or larger units at the margin would yield larger differences

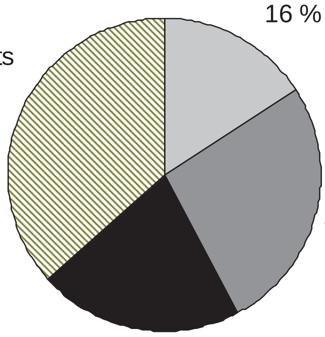


- Deterministic gets more expensive than stochastic in jumps
  - Certain situations yield the difference (for example nuclear unit is not started up in time)



VTT TECHNICAL RESEARCH CENTRE OF FINLAND 16/03/2010 6

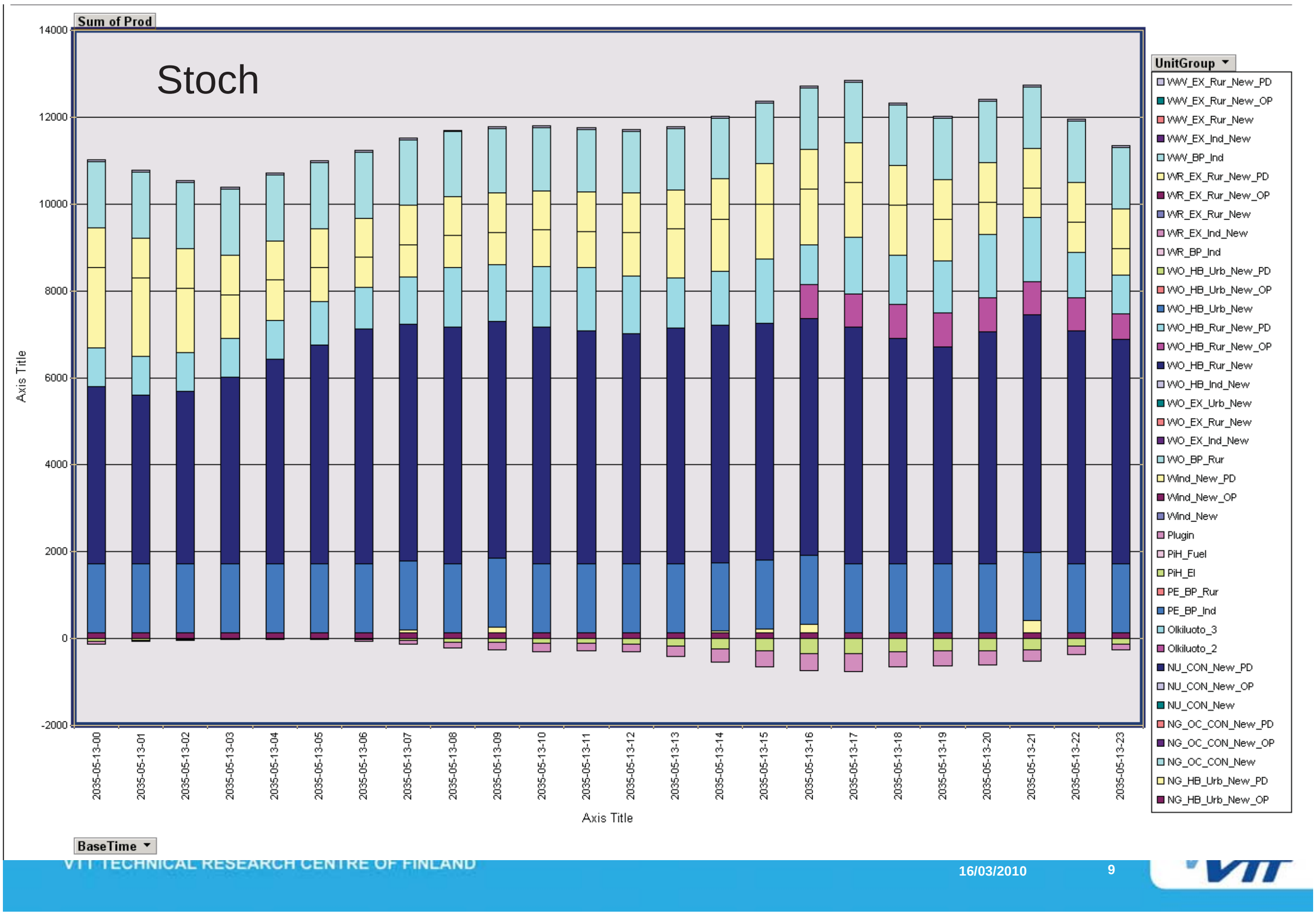
THE BENEFITS OF SMART EVs CUT UP
Total system benefit of 205 €/vehicle/year

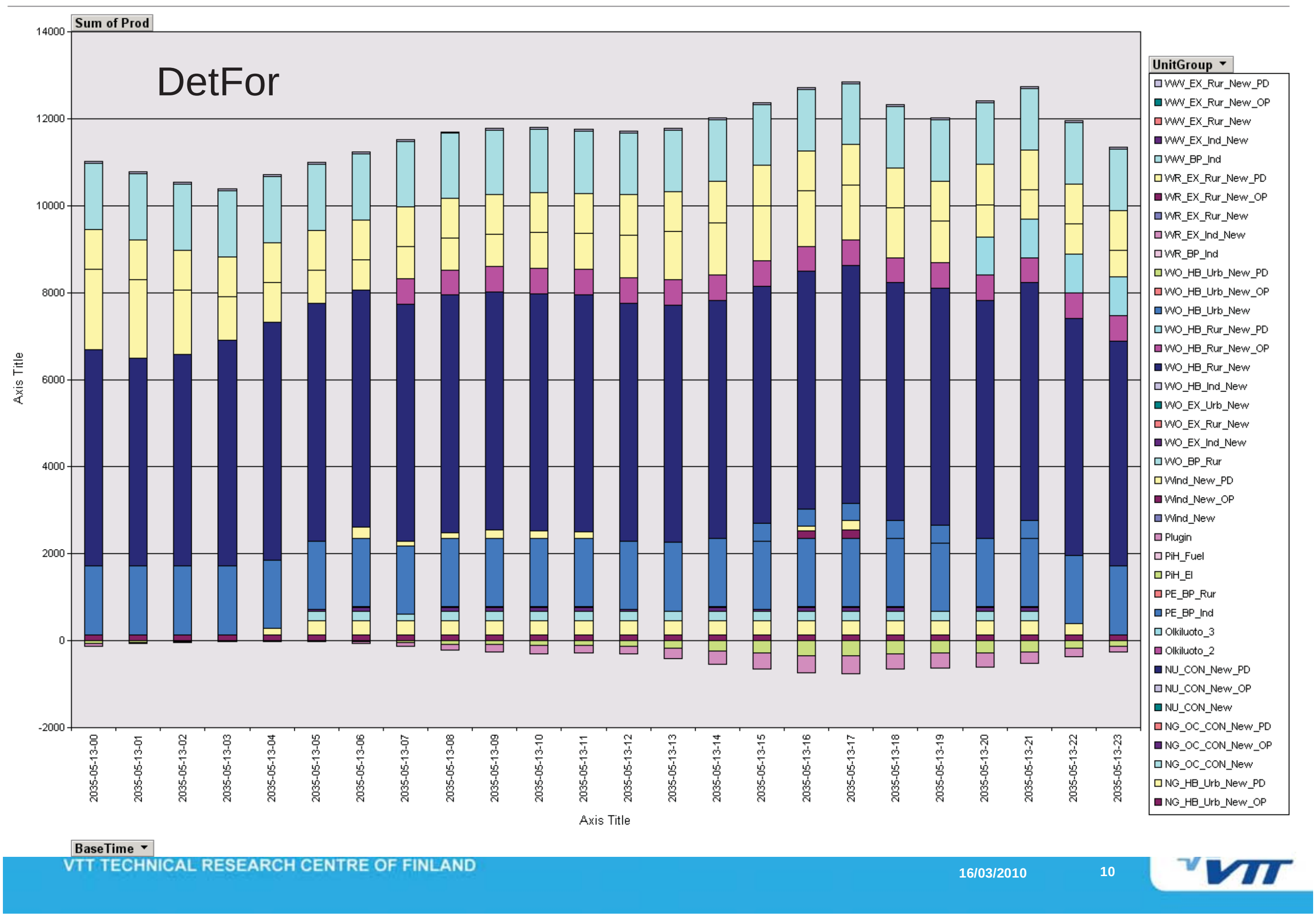


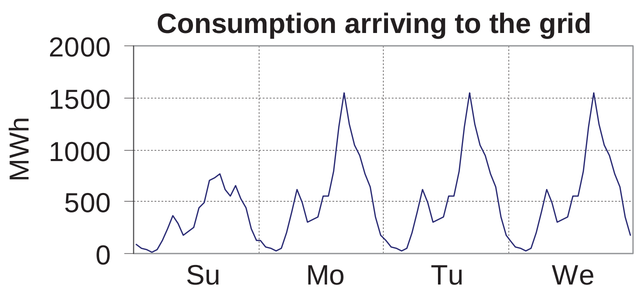
VTT TECHNICAL RESEARCH CENTRE OF FINLAND 16/03/2010 7

VTT creates business from technology

VTT TECHNICAL RESEARCH CENTRE OF FINLAND 16/03/2010 8

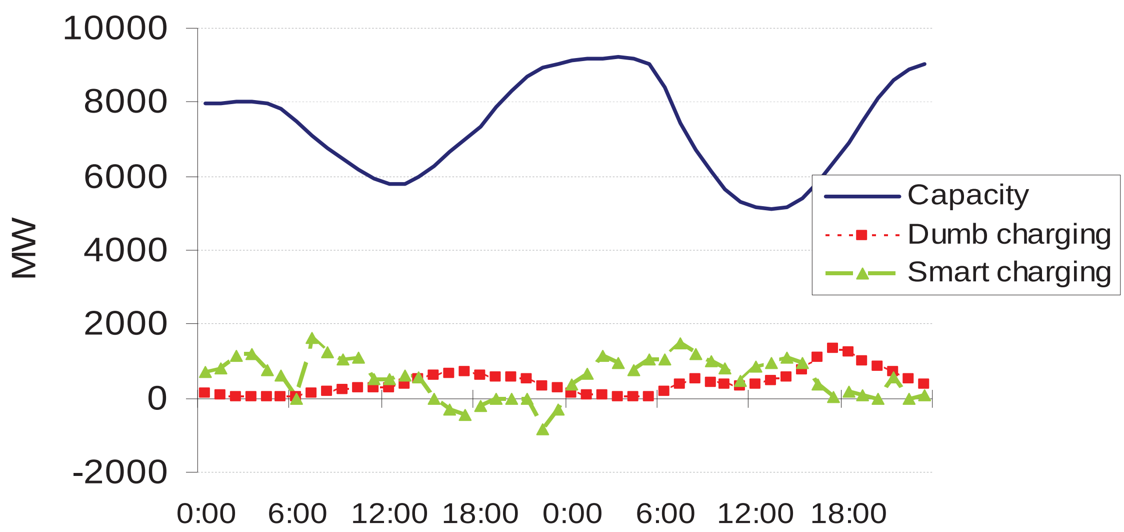

Sum of Prod
Stoch
14000
12000
10000
8000
6000
4000
2000
0
-2000
Axis Title
2035-05-13-00
2035-05-13-01
2035-05-13-02
2035-05-13-03
2035-05-13-04
2035-05-13-05
2035-05-13-06
2035-05-13-07
2035-05-13-08
2035-05-13-09
2035-05-13-10
2035-05-13-11
2035-05-13-12
2035-05-13-13
2035-05-13-14
2035-05-13-15
2035-05-13-16
2035-05-13-17
2035-05-13-18
2035-05-13-19
2035-05-13-20
2035-05-13-21
2035-05-13-22
2035-05-13-23
Axis Title
UnitGroup
WW_EX_Rur_New_PD
WW_EX_Rur_New_OP
WW_EX_Rur_New
WW_EX_Ind_New
WW_BP_Ind
WR_EX_Rur_New_PD
WR_EX_Rur_New_OP
WR_EX_Rur_New
WR_EX_Ind_New
WR_BP_Ind
WO_HB_Urb_New_PD
WO_HB_Urb_New_OP
WO_HB_Urb_New
WO_HB_Rur_New_PD
WO_HB_Rur_New_OP
WO_HB_Rur_New
WO_HB_Ind_New
WO_EX_Urb_New
WO_EX_Rur_New
WO_EX_Ind_New
WO_BP_Rur
Wind_New_PD
Wind_New_OP
Wind_New
Plugin
PiH_Fuel
PiH_El
PE_BP_Rur
PE_BP_Ind
Olkiluoto_3
Olkiluoto_2
NU_CON_New_PD
NU_CON_New_OP
NU_CON_New
NG_OC_CON_New_PD
NG_OC_CON_New_OP
NG_OC_CON_New
NG_HB_Urb_New_PD
NG_HB_Urb_New_OP
BaseTime
VTT TECHNICAL RESEARCH CENTRE OF FINLAND
16/03/2010
9
VTT


Sum of Prod
DetFor
14000
12000
10000
8000
6000
4000
2000
0
-2000
Axis Title
2035-05-13-00
2035-05-13-01
2035-05-13-02
2035-05-13-03
2035-05-13-04
2035-05-13-05
2035-05-13-06
2035-05-13-07
2035-05-13-08
2035-05-13-09
2035-05-13-10
2035-05-13-11
2035-05-13-12
2035-05-13-13
2035-05-13-14
2035-05-13-15
2035-05-13-16
2035-05-13-17
2035-05-13-18
2035-05-13-19
2035-05-13-20
2035-05-13-21
2035-05-13-22
2035-05-13-23
Axis Title
UnitGroup
WW_EX_Rur_New_PD
WW_EX_Rur_New_OP
WW_EX_Rur_New
WW_EX_Ind_New
WW_BP_Ind
WR_EX_Rur_New_PD
WR_EX_Rur_New_OP
WR_EX_Rur_New
WR_EX_Ind_New
WR_BP_Ind
WO_HB_Urb_New_PD
WO_HB_Urb_New_OP
WO_HB_Urb_New
WO_HB_Rur_New_PD
WO_HB_Rur_New_OP
WO_HB_Rur_New
WO_HB_Ind_New
WO_EX_Urb_New
WO_EX_Rur_New
WO_EX_Ind_New
WO_BP_Rur
Wind_New_PD
Wind_New_OP
Wind_New
Plugin
PiH_Fuel
PiH_El
PE_BP_Rur
PE_BP_Ind
Olkiluoto_3
Olkiluoto_2
NU_CON_New_PD
NU_CON_New_OP
NU_CON_New
NG_OC_CON_New_PD
NG_OC_CON_New_OP
NG_OC_CON_New
NG_HB_Urb_New_PD
NG_HB_Urb_New_OP
BaseTime
VTT TECHNICAL RESEARCH CENTRE OF FINLAND
16/03/2010
10
VTT



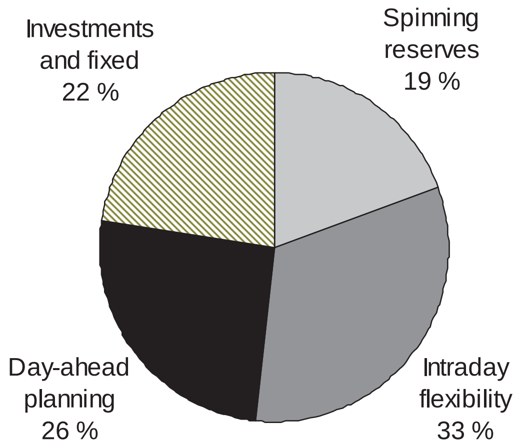
VTT TECHNICAL RESEARCH CENTRE OF FINLAND 16/03/2010 11

CHARGING BEHAVIOR
example of model results



VTT TECHNICAL RESEARCH CENTRE OF FINLAND 16/03/2010 12

THE BENEFITS OF SMART EVs CUT UP
Total system benefit of 172 €/vehicle/year



VTT TECHNICAL RESEARCH CENTRE OF FINLAND 16/03/2010 13

STOCHASTIC/DETERMINISTIC AND MIP/LP COMPARISON

Annual system cost (M€) in different modes

Increase in annual system costs with 'dumb' or 'smart' Evs

Consumption has increased by 3.48%

	No EVs	Dumb	Smart
Stoch MIP	4745	4.71 %	1.24 %
Stoch LP	4739	4.71 %	1.32 %
DetFor MIP	4751	4.69 %	1.29 %
DetFor LP	4746	4.68 %	1.34 %

Smart EVs decrease start-ups

Stochastic information adds value to the EV optimisation

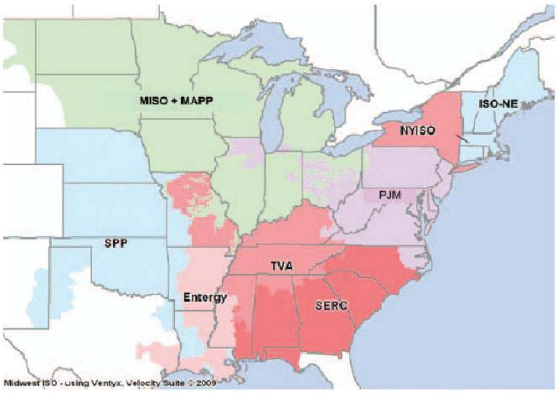
Very small differences
–
Lot of small units in the system

VTT TECHNICAL RESEARCH CENTRE OF FINLAND 16/03/2010 14

Advanced Unit Commitment in the Eastern Interconnect

- Project Team
  - NREL – Project Management, data and modeling for the US
  - Risoe DTU – developer of the Scheduling Model
  - Univ Stuttgart IER – developer of the Scenario Tree Tool
  - ECAR – Assistance on analysis and model runs
- Objectives
  - Understand the impacts of forecast error on the eastern interconnect
  - Understand the impacts and benefits of stochastic planning on the eastern interconnection
  - Understand the impacts and benefits of rolling UC updates on the eastern Interconnection
- Scope
  - Uses the WILMAR tool
  - Uses consistent data with Eastern Wind Integration and Transmission Study
  - Three data years, 4 unit commitment scenarios, sensitivity requiring coal as must run

Study System



EWITS Scenario 2:
“Hybrid with Offshore”

Region	Onshore (MW)	Offshore (MW)	Total (MW)	Annual Energy (TWh)
ISO-NE	8,837	5,000	13,837	46
MISO+MAPP	69,444	0	69,444	288
NYISO	13,887	2,620	16,507	48
PJM	28,192	5,000	33,192	97
SERC	1,009	4,000	5,009	16
SPP	86,666	0	86,666	245
TVA	1,247	0	1,247	4
Total	209,282	16,620	225,902	745

The WILMAR tool

- Improve decision making by using information contained in wind power production and load forecasts
- Information: Expected wind power production and load, but also precision of forecast, i.e. the distribution of the wind power production forecast errors
- Information accuracy improves as you get closer to real-time

- **Stochastic Planning**: Planning with representation of stochastic variables to provide for a more robust system
- **Rolling Planning**: Using updated information to adjust unit commitment decisions more frequently.

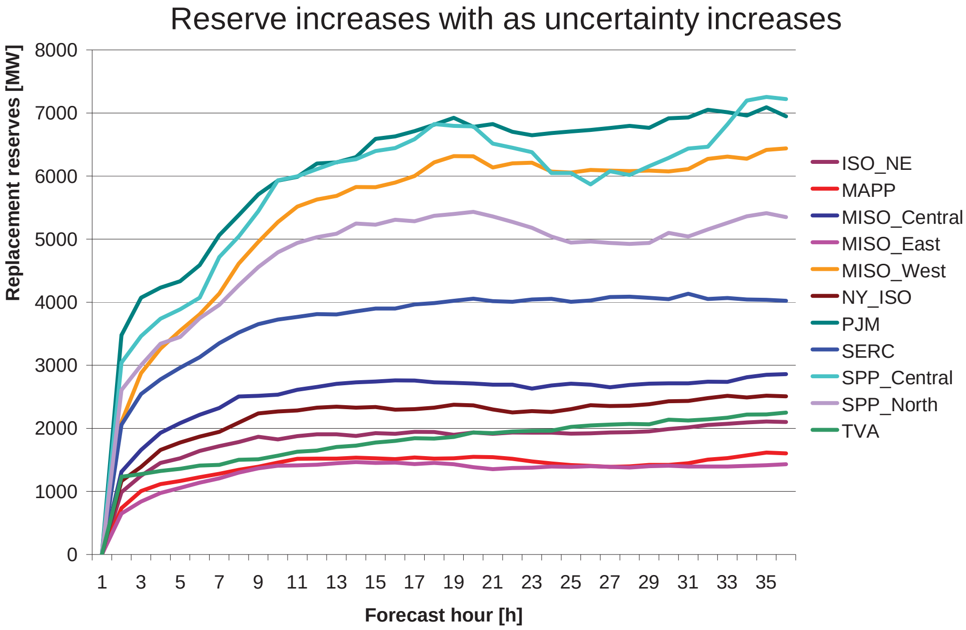
The WILMAR tool

- How:
  - Build system-wide stochastic optimisation model with the wind power production and load as a stochastic input parameter
  - Covering both day-ahead scheduling and rescheduling due to updated wind power and load forecasts
- Consequence: Model makes unit commitment and dispatch decisions being robust towards wind power production and load forecast errors

Scenario Tree Tool

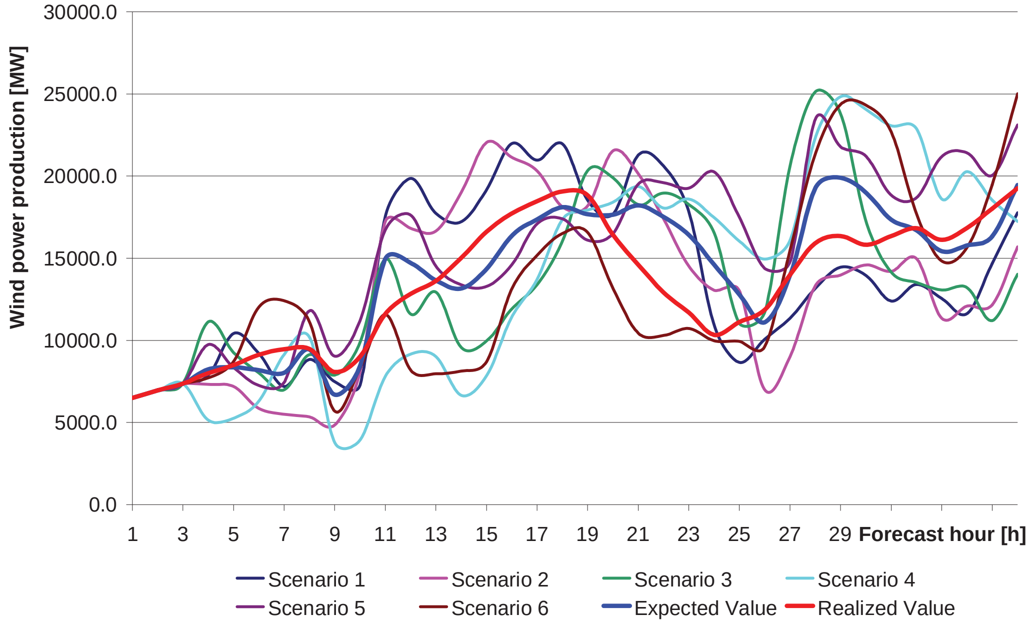
- Generation of scenario trees containing stochastic input parameter for Scheduling Model:
  - Wind power forecasts
  - Load forecasts
  - Demand for replacement reserves
- Generation of Semi-Markov processes describing availability / unavailability of power plants
- Implemented in Matlab
- Replacement reserve (positive reserves for different forecast horizons):
  - Demand time and scenario dependant (determined for forecast horizons from 1 hour to 36 hours ahead)
  - Demand dependant on wind power and load forecasts
  - Offline units can provide this type of reserve if they have start-up times of less than an hour

Replacement Reserves



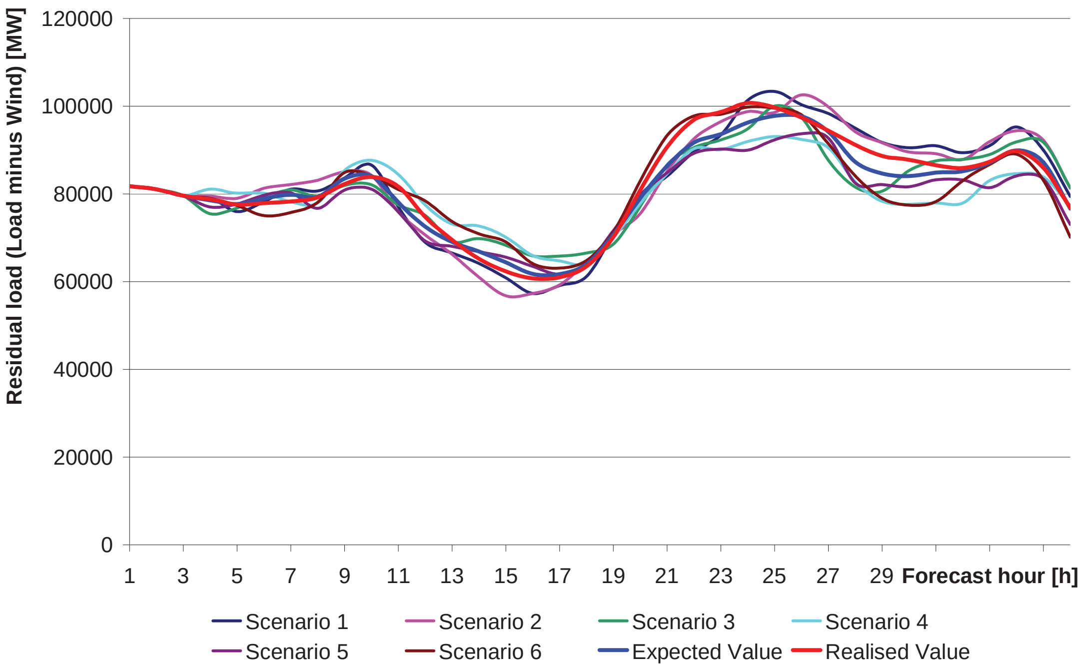
Risø DTU, Technical University of Denmark

Example Wind Forecasts



Risø DTU, Technical University of Denmark

Example day-ahead scenario tree for PJM net load



Risø DTU, Technical University of Denmark

8

Scheduling model

- First three hours in scenario tree deterministic:
  - Realized wind power production
  - Realized load
  - Demand replacement reserve (taking uncertainty in wind power production forecasts and load forecasts for forecast horizons 1 to 3 hours ahead into account)
- Optimization over all outcomes represented by the scenario tree taking both demands for electricity and demand for spinning and replacement reserves into account
- Minimization of expected costs. Expectation taken over branches in scenario tree
- Unit restrictions: minimum up time, minimum down time, start-up time, minimum stable operation level, piece-wise linear fuel consumption curve, restriction on ability to provide spinning reserve, ramp up rates, ramp down rates, etc.
- Implemented in GAMS using CPLEX solver

Risø DTU, Technical University of Denmark

9

Representation of transmission grid

- Model area divided into EWITS regions
- Regions connected by transmission lines
- No grid representation within a region (only average transmission and distribution loss)
- Energy exchange between regions. Grid restrictions expressed by usage of NTCs (net transfer capacities)
- Monthly NTCs obtained from Promod load flow calculations

Risø DTU, Technical University of Denmark

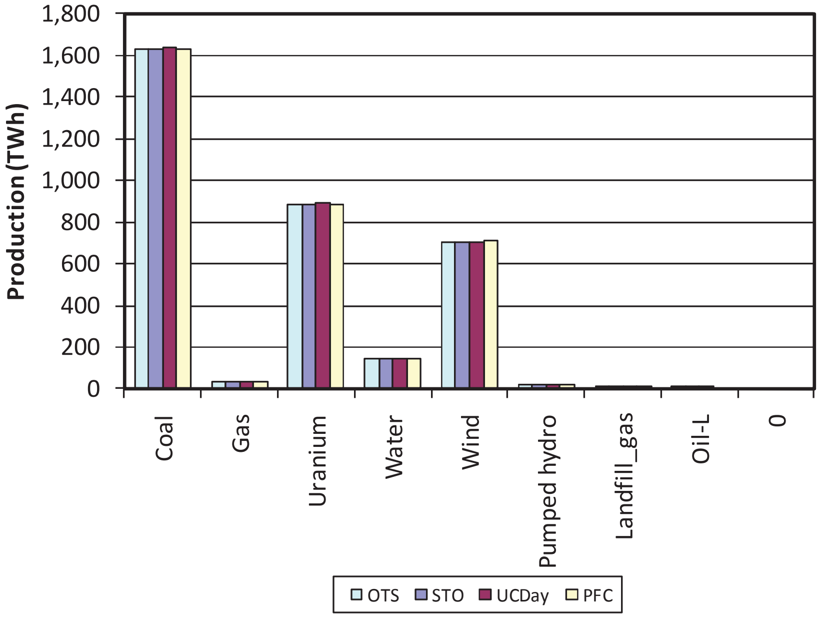
10

Results

- Model runs:
  - **STO:** Stochastic planning using scenario trees with six branches (six forecasts), unit commitment updated every 3 hours
  - **UCDay:** Stochastic planning, unit commitment for units with start times greater than 1 hour, updated once per day in the day-ahead market
  - **OTS:** Deterministic planning with forecast error (only one forecast), unit commitment updated every three hours
  - **PFC:** Deterministic planning with perfect foresight i.e. wind power and load forecasts corresponds to realized wind power and load.
- Comparisons of these model runs gives insight into the differences of forecast error, stochastic planning, and rolling UC updates

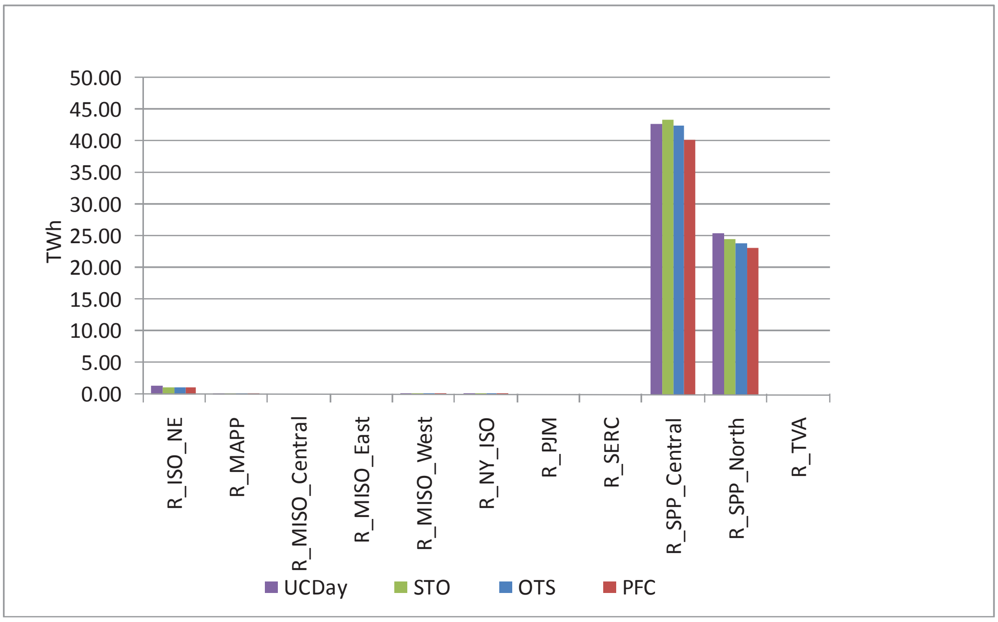
Risø DTU, Technical University of Denmark 11

Power production distributed on fuel type



12 Risø DTU, Technical University of Denmark Title of the presentation 21-aug-2008

Wind curtailment

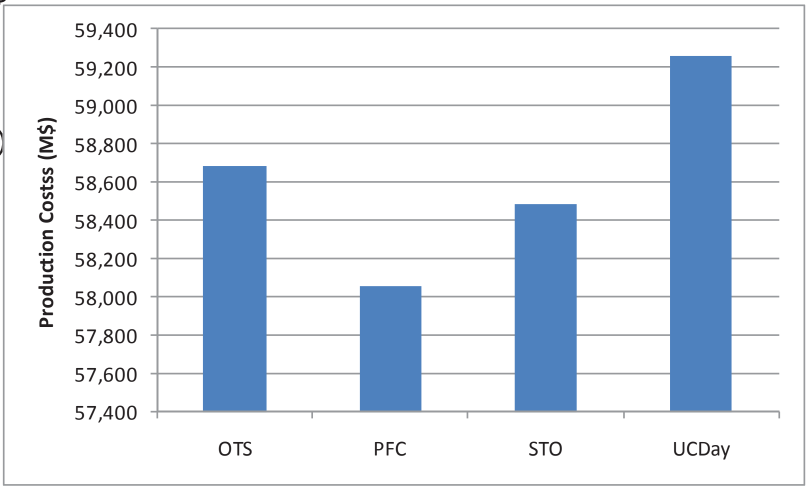


Cost differences must run coal – coal not must run

	OTS (M$)	PFC (M$)	STO (M$)	UCDay (M$)
Coal Must-Run	60803	60457	61111	61035
Coal Non-Must-Run	58688	58055	58481	59259
Coal Must Run - increase vs. STO	-0.5%	-1.1%	0.0%	-0.1%
Coal Non Must Run - increase vs. STO	0.4%	-0.7%	0.0%	1.3%
Increase with coal must run	-3.6%	-4.1%	-4.5%	-3.0%

Operational costs (mainly fuel costs)

- Value intra-day rescheduling: 778 M$ (1.3%) (UCDay minus STO)
- Value stochastic UC: 207 M$ (0.36%) (OTS minus STO)
- Value perfect foresight: 426 M$ (0.7%) (STO minus PFC)
- It appears rolling unit commitment gives more value than stochastic planning



Risø DTU, Technical University of Denmark

Acknowledgements

Hannele Holttinen, Senior Research Scientist and Research Coordinator, VTT Technical Research Centre of Finland
Hannele Holttinen is acknowledged for her great job as Operating Agent for task 25. Hannele has also been most helpful providing information for this report.

DTU Wind Energy is a department of the Technical University of Denmark with a unique integration of research, education, innovation and public/private sector consulting in the field of wind energy. Our activities develop new opportunities and technology for the global and Danish exploitation of wind energy. Research focuses on key technical-scientific fields, which are central for the development, innovation and use of wind energy and provides the basis for advanced education at the education.

We have more than 230 staff members of which approximately 60 are PhD students. Research is conducted within 9 research programmes organized into three main topics: Wind energy systems, Wind turbine technology and Basics for wind energy.

Technical University of Denmark
DTU Vindenergi
Frederiksborgvej 399
Building 118
4000 Roskilde
Denmark
Telefon 46 77 50 85
info@vindenergi.dtu.dk
www.vindenergi.dtu.dk