Design and Operation of Power Systems with Large Amounts of Wind Power, IEA collaboration

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New R&D collaboration on "Design and Operation of Power Systems with Large Amounts of Wind Power Production" has been formed in IEA Wind. The R&D task will 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. This paper outlines the power system impacts of wind power, the national studies published and on-going and describes the goals of the international collaboration. There are dozens of studies made and ongoing related to cost of wind integration, however, the results are not easy to compare. An in-depth review of the studies is needed to draw conclusions on the range of integration costs for wind power. State-of-the art review process will seek for reasons behind the wide range of results for costs of wind integration – definitions for wind penetration, reserves and costs; different power system and load characteristics and operational rules; underlying assumptions on variability of wind etc.

I. Introduction

THE existing targets for wind power anticipate a quite high penetration of wind power in many countries. It is technically possible to integrate very large amounts of wind capacity in power systems, the limits arising from how much can be integrated at socially and economically acceptable costs. So far the integration of wind power into regional power systems has mainly been studied on a theoretical basis, as wind power penetration is still rather limited in most countries and power systems. However, already some regions (e.g. West Denmark, North of Germany and Galicia in Spain) show a high penetration and have first practical experience from wind integration.

Wind power production introduces more uncertainty in operating a power system: it is variable and partly unpredictable. To meet this challenge, there will be need for more flexibility in the power system. How much extra flexibility is needed depends on the one hand on how much wind power there is and on the other hand on how much flexibility there exists in the power system.

In recent years, several reports have been published in many countries investigating the power system impacts of wind power. However, the results on the costs of integration differ and comparisons are difficult to make due to different methodology, data and tools used, as well as terminology and metrics in representing the results. Estimating the cost of impacts can be too conservative for example due to lack of sufficient data. An in-depth review of the studies is needed to draw conclusions on the range of integration costs for wind power. This requires international collaboration. As system impact studies are often the first steps taken towards defining wind penetration targets within each country it is important that commonly accepted standard methodologies are applied related to these issues.

A new R&D Task titled "Design and Operation of Power Systems with Large Amounts of Wind Power Production" has been formed within the "IEA Implementing Agreement on the Co-operation in the Research, Development and Deployment of Wind Turbine Systems" [1]. The work has started in the beginning of 2006 and will continue for three years. This R&D task will collect and share information on the experience gained and the studies made, with analyses and guidelines on methodologies.

II. Power System Impacts of Wind Power

Wind power has impacts on power system reliability and efficiency (Fig 1). These impacts can be either positive or negative. Power system reliability consists of system security and adequacy. The system adequacy describes the amount of production and transmission capacity in varying load situations. The security of the power system is maintained by planning and operating the system in a way that minimises disturbances caused by faults. In order to manage disturbances, the system responsible grid operator secures that the system has enough reserves in power plants and in the transmission grid and keeps power transfers within the allowed limits.

Different time scales usually mean different models (and data) used in impact studies. The case studies for the system wide impacts can thus fall into following:

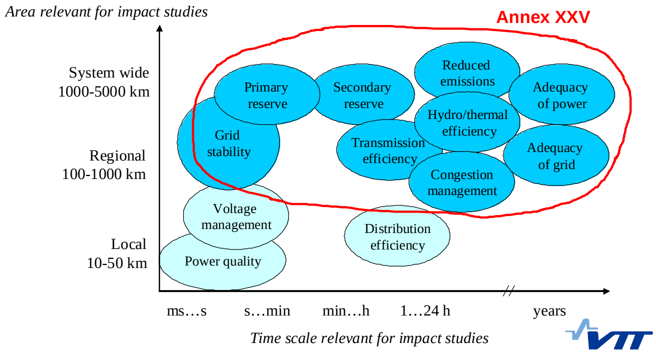

Fig. 1. Impacts of wind power on power systems, divided in different time scales and width of area relevant for the studies.In this international collaboration (IEA WIND Task 25), local issues of grid connection like power quality are not addressed but the more system related issues.

Regulation and load following: reserve/regulating power (time-scale minute…half an hour). How the uncertainty introduced by wind power will affect the allocation and use of reserves in the system. Unpredicted part of the variations of large area wind power should be combined with any other unpredicted variations the power system sees, like unpredicted variations in load. There are several studies made already, and analysing the study methods is important as the results vary. General conclusions on increase in balancing requirement will depend on region size relevant for balancing, initial load variations and how concentrated/distributed wind power is sited. The costs will depend on the marginal costs for providing regulation or mitigation methods used in the power system. Market rules will also have an impact, so technical costs can be different from market costs.

Efficiency and unit commitment: prediction errors of wind power (time scale: hours…days). Here the interest is on how the conventional capacity is run and how the variations and prediction errors of wind power change the unit commitment: both the time of operation and the way the units are operated (ramp rates, partial operation, starts/stops). There are difficulties in using the existing planning tools, because they do not take into account wind power uncertainties in a most correct way and sometimes ignore existing flexibilities in the system. Analysing and developing methods of incorporating wind power into these models is important. The simulation results give insight into the technical impacts that wind power has, and also the (technical) costs involved. In electricity markets, prediction errors of wind energy can result in high imbalance costs. Analyses on how current market mechanisms affect wind power producers is also important.

Adequacy of power: total supply available during peak load situations (time scale: several years). The reliability of the power system includes the analyses for ensuring sufficient electricity production within the system to meet the load demand or constraints within the transmission and distribution system. System adequacy is associated with static conditions of the system, and studied either by a simple generation-load model or by an extended bulk transmission system model consisting of generation, transmission, distribution and load. The estimation of the required production needs includes the system load demand and the maintenance needs of production units (reliability data). The criteria that are used for the adequacy evaluation include the loss of load expectation (LOLE), the loss of load probability (LOLP) and the loss of energy expectation (LOEE), for instance. There are plenty of studies on the capacity credit of wind power in different systems. However, the quantification of this as a cost has been more controversial.

Transmission adequacy and efficiency: (time scale hours to years). The impacts of wind power on transmission depend on the location of wind farms relative to the load, and the correlation between wind power production and load consumption. Wind power affects the power flow in the network and may even change the power flow direction in parts of the network. The changes in use of the power lines can bring about power losses or benefits. Increasing wind power production can affect potential bottleneck situations. Depending on its location wind power may at its best reduce bottlenecks, but at another location result in more frequent bottlenecks. A special problem is situations of strong winds that cause sudden reduction of cross-border trade capacity. Grid adequacy means assessment of grid reinforcement within regional development planning. Also maximum use of existing investments is of primary interest for network operators. Alternatives to new power line investments are increased power line utilization degree by the use of online information (temperature, loads), increase of maximum transmission capacity by introducing new components like FACTS or replacing existing components (conductors, transformers), and of course wind farm output control. When determining adequacy of grid both steady-state load flow and dynamic system stability analysis is needed.

System stability: (time scale seconds to minutes). Different turbine types have different characteristics and consequently also different possibilities to support the system when a disturbance occurs. The siting of wind farms relative to load centres will have some influence on this issue as well. For system stability reasons operation and control properties similar to central power plants are required for wind farms at some stage. System stability studies of different wind turbine technologies are needed in order to test and develop advanced control strategies and possible use of new components (f.ex. FACTS) at wind farms.

III. Objectives of the IEA Collaboration

The IEA R&D Task 25 “Design and Operation of Power Systems with Large Amounts of Wind Power” has started in the beginning of 2006 and will continue for three years. The ultimate objective is to provide information to facilitate the highest economically feasible wind energy penetration within electricity power systems worldwide. This Task supports this ultimate goal by analysing and further developing the methodology to assess the impact of wind power on power systems. The main emphasis is on the impacts that wind power has on reliability and on efficiency (losses) of the power system.

The task will establish an international forum for exchange of knowledge and experiences related to power system operation with large amounts of wind power. The challenge is to create coherence between parallel activities:

International Council on Large Electric Systems CIGRE, Utility Wind Integration Group UWIG and European Transmission System Operators ETSO, as well as other R&D Task work in Wind and DSM Implementing Agreements. IEA Wind R&D Task 21 on dynamic models for wind power will end as this task starts. Task 21 work has improved the wind turbine and wind farm models used in dynamic grid studies and provided this task with tools to use. Task 24 on wind and hydro power integration has started one year before and all the case studies are highly relevant for this task as well. It is however considered useful to keep wind and hydro integration as a separate task: as the problem setting for multi constraint and river system hydro power is demanding, there would not be time for detailed enough discussions in a wide scope task like Task 25 is.

The participants will collect and share information on the experience gained and the studies made up to and during the task, analyse the data and tools used in the studies and process guidelines on methodologies used to determine the impact of wind power on power systems. The case studies will address different aspects of power system operation and design: reserve requirements, balancing and generation efficiency, capacity credit of wind power, efficient use of existing transmission capacity and requirements for new network investments, bottlenecks, cross-border trade and system stability issues. The main emphasis is on the technical operation: the impact that wind power has on reliability and efficiency of the power system. Costs will be assessed when necessary as a basis for comparison. Also technology that mitigates impacts of wind power and supports enhanced penetration will be addressed by communicating successful concepts: modification of wind farm controls and operating procedures; dynamic line ratings; storage; demand side management DSM etc.

The Task will start with producing a state-of-the-art report on the knowledge and results so far and end with developing guidelines on the recommended methodologies when estimating the system impacts and the costs of wind power integration. Also best practice recommendations may be formulated on system operation practices and planning methodologies for high wind penetration.

IV. National Case Studies

Challenges for the case studies include developing representative wind power production time series in near real time across the area of study, taking into account the (smoothed out) variability and uncertainty (prediction errors) and then modelling the resultant power system operation. Beyond that, optimisation of the integrated system should be explored. In order to facilitate the highest economically feasible wind energy penetration within power systems, modifications to system configuration and operation practices to accommodate high wind penetration may be required. Not all current system operation techniques are designed to correctly incorporate the characteristics of wind generation and surely were not developed with the objective in mind.

A wide range of case studies from different power systems have already been made and case studies will also be made during the 3 years. The national case studies address different impacts: balancing; grid congestions, reinforcement and stability; power adequacy; impact of wind farm technology and control to stability; increased flexibility and value of DSM/storage; forecast model experience; wind and hydro interaction; generation mix and operation methodologies to support a high penetration of wind power.

A. Denmark

Existing publications on wind integration have been made by the TSO Energinet.dk [2], Risø [3], Ålborg University [4]. Risø is reporting from EU projects Anemos (Prediction tools), SUPWIND (energy system modeling) and Nightwind (storage).

Risø is one of the core developers and users of the Wilmar Planning tool enabling detailed analysis of the planning of the unit commitment and dispatch of power plants on the day-ahead market subject to stochastic wind power forecast errors and the corresponding replanning on the subsequent intra-day and regulating power markets. The work will continue in SUPWIND EU project 2006-2008.

There is ongoing national research for increased flexibility in the power system (demand side and/or storage), for example Vanadium batteries in the power system. Focus in these projects is not only on balancing issues but also on system stability and grid issues.

B. Finland

PhD work on large scale wind power in the Nordic power system was published in 2004 [5].

Ongoing studies include a PhD work on large share of wind and renewable energy in the Finnish energy system and case studies simulating the effects of large wind power in the North of Norway and Finland on the Finnish North-South bottleneck situations and simulating the effect of wind power prediction errors to one energy producer with limited amount of hydro power. The national research includes also activities related to load flow analysis of different siting options of 4000 MW wind power in Finland and neighbouring areas. Also the impact of different wind power technologies on system stability will be made, together with VTT and Technical University of Helsinki.

C. Germany

The main existing study covering wind integration in Germany is German Energy Agency’s (dena) study “Planning of the integration of wind energy into the German grids ashore and offshore regarding the economy of energy supply”, published in 2005 [6].

ISET (Institut für Solare Energieversorgungstechnik) works on several projects regarding the integration of renewable energies into electrical power supply: sequentially further-developed software tools for the determination of the current wind power feed (online-model) and short term prediction for the German TSOs E.ON Netz (ENE), RWE Transportnetz Strom (RWE) and Vattenfall Europe Transmission (VE-T). The combination of the on-line and prediction model forms the basis for the immediate horizontal exchange of the wind energy fed between the German TSOs. ISET is also coordinating German national network "Energy and Communication" and participating in the following European projects related to wind energy: Upwind (Integrated Project), POWWOW (Coordinated Action), Reliance (Coordinated Action) and Wind on the grid (Specific Targeted Research Project).

A national project “Integration of large offshore wind farms into electricity grids” is a co-operation with the Transmission Grid Operators ENE and VE-T, the wind turbine manufacturer Enercon, the German weather forecast service Deutsche Wetterdienst, and the Kassel University. Measures optimising the economy and the safety of grid operation are studied. Objectives of this project are to develop and test concepts for the control of large wind farms ashore and offshore as well as management systems for the grid operation and the power plant dispatching.

A national research project on power systems operation with high penetration of renewable energy is coordinated by Ecofys. One aspect of the project is a simulation study covering the High and Extra High Voltage network of Germany, where major network congestions are identified and combined with an estimate of their respective probabilities taking into account near term growth of wind power.

There will be a continuation for the German Energy Agency’s (dena) study “Planning of the integration of wind energy into the German grids ashore and offshore regarding the economy of energy supply”.

D. Ireland

The Irish (Republic of Ireland and Northern Ireland) power system presents specific challenges for integrating high levels of wind energy because of its relatively small size and low level of interconnection with other systems. The system characteristics which present challenges are low system inertia, large frequency excursions, tight capacity margins, a high ratio of average generating plant size to overall system size and regional network constraints.

Investigations into the effects of integrating wind power into the Irish electricity system and the limits to wind energy penetration date from 1990. Many of the earlier studies on wind energy in the Irish power system looked solely at transmission network issues rather than effects upon the generating system. As the penetration of wind power in the Irish system is now rising rapidly there has more recently been a greater urgency on examining the complete system effects. A summary of the most recent studies to date and their key findings is as follows:

- 2004 ESBNG Report “Impact on Wind Power Generation in Ireland on the Operation of Conventional Plant” [7]. The wind input assessment methodology used was direct scaling of output data from existing WPP combined with some planned site wind data to create a power time series. The system assessment methodology was generating system simulation using a unit commitment and despatch simulator. The study found that a high wind energy penetration greatly increased the number of start ups and ramping for gas turbine generation in the system and that the cost of using wind power for CO_2 abatement in the Irish electricity system is €120/Tonne.
- 2004 SEI ILEX/UMIST/UCD/QUB Report “Operating Reserve Requirements as Wind Power Penetration Increases in the Irish Electricity System” [8]. The wind input assessment methodology within this study was to use a time series generated from statistical manipulation of historic wind farm data. The system assessment methodology was generating system simulation using a proprietary system dynamic model. The study findings were that fuel cost and CO_2 savings up to a 1500MW wind power penetration in the ROI system were directly proportional to the wind energy penetration. It found that while wind did reduce overall system operation costs it could lead to a small increase in operating reserve costs.
- 2004 ESBI Report for SEI “Renewable Energy Resources for Ireland 2010 & 2020”. The wind input assessment methodology in this study was to use the economically viable resource based upon the 2003 wind atlas (SEI). The system assessment methodology used results from ESBNG 2004 study detailed above to find limits on wind energy penetration of 1000MW in 2010 and 1250MW in 2020. The report also found that if replacement plant for conventional plant retired in 2016 were aeroderivative OCGT rather than CCGT the 2020 limit became 3500MW.
- 2004 SEI Brattle Group Report for SEI “Renewable Energy in the New Irish Electricity Market”. The wind input assessment methodology was a time series from the SEI study on regulating reserves. The system assessment methodology used generating system despatch simulation (Henwood) to examine the effects upon conventional plant. The study found that the costs of ramping & start-ups were reasonable for a 1500MW wind energy penetration.
- 2004 IWEA Milborrow/Duggan Report – Presentations on this study indicated that 3500MW wind energy penetration is feasible in the Irish electricity system with an appropriate conventional generation mix. The report of this study remains unpublished.

In 2005 an All-Island Grid Study was requested by the Governments of the Republic of Ireland and Northern Ireland to inform renewable energy policy to 2020. As wind power is will be the dominant renewable electricity generation technology in Ireland up until 2020 the study has a primary focus on the system effects of a high wind penetration. It is being executed in four modules or “workstreams” which will run concurrently and be contracted to independent consultants. Workstream 1 will examine renewable energy resources up to 2020, in order that the effects upon system operation may be modelled. A particular focus will be on the spatial distribution of the wind farms for optimal exploitation of the wind resource. It will create a number of alternative spatial deployment scenarios also taking into account wind resource cost curves. Workstream 2 shall be comprised of two stages; (a) an initial high-level modelling stage to identify a profile of the lowest cost renewable energy mix to achieve a given set of potential renewable energy penetration targets in electricity generation in 2020; (b) a detailed modelling stage which shall include simulations of actual 2020 generating plant commitment and dispatch with various projected penetration scenarios. It is part of the study scope to propose a new operation methodology for future high RE penetration. Workstream 3 will investigate electricity network development options for a range of renewable generation penetration levels. Workstream 4 will investigate the economic impact and benefits of various renewable generation levels. It combines the first three tasks to determine the impact of the rate of renewable energy penetration on the cost burden for the various electricity sector stakeholder groups. The task will also recommend any likely/necessary changes to market arrangements to facilitate the various levels of penetration.

E. Netherlands

In 2003 the Ministry of Economic Affairs of The Netherlands initiated a study on the effects of 6000 MW offshore wind on the Dutch grid. The study started with determining the best locations for 6000 MW wind power and investigating the options to transport the power to the on-shore substation. This part of the study concluded that for the relatively short distances between wind farms and substation, AC connections are to be preferred. In the second part of the study, the consequences for the 150/380 kV grid of The Netherlands have been determined by a load flow study. This showed that additional voltage control equipment is required and that a limited number of lines have to be upgraded. In 2005 the Connect 6000 study was continue by investigating the phased introduction of offshore wind power according to the ECN-CPB scenarios of September 2005. Different options of connecting the wind farms have been compared from an economic as well as a spatial and planning point of view. The study was completed by investigating the legal and political aspects of large scale offshore wind power.

Apart from dedicated research initiatives like the Connect 6000 studies, two research programmes currently exist in The Netherlands: in the we@sea consortium, a collaboration of research institutes and industry, research line 3 investigates the technical aspects of offshore wind power electricity transport and the interaction of wind farms and the grid. The second programme, called EOS, includes a research theme dedicated to future grid design in combination with a substantial increase in renewable production (large scale as well as decentralised).

ECN and TUD participate in we@sea as well as EOS. Currently, the emphasis at ECN is on development and validation of dynamic models for wind farms, while TUD concentrates on two themes: improving local wind farm-grid and distributed generation-grid interaction and balancing production and demand with a large amount of offshore wind.

F. Norway

Recent and ongoing studies include:

- Development of numerical wind farm models for use in power system simulation tools. The models include fixed speed wind turbines with squirrel cage induction generator, variable speed wind turbines with doubly fed induction generator and variable speed wind turbines with full-scale frequency converter. The work has been prepared as part of IEA Wind R&D Task 21 with funding from the Research Council of Norway, but also under contract with utilities and system operators [9].
- Power system stability studies have been prepared in conjunction with planning of large wind farms at various sites in Norway, but also more generic type of studies have been prepared as part of projects for the Research Council of Norway and EU. Example publications are [10, 11, 12, 13].
- Studies on wind/hydro integration have focused on planning and operation of large wind farms in areas with limited power transfer capacity, [14, 15]. The studies involve assessment of system operation, wind and hydro variations and hour-by-hour simulations. It is shown that surprisingly large amounts of wind power can be integrated without costly grid reinforcements, but utilizing the control possibilities of modern wind farms. The studies have been prepared for IEA Wind R&D Task 24, but are also highly relevant for IEA Wind R&D Task 25.

A new study is being planned for assessing the impact of large scale wind power on system adequacy in a regional hydro-based power system with weak interconnections. Other relevant themes of study are a) calculation of required national regulation capacity depending of wind energy share, b) market solutions for cost effective integration of wind power and c) using Nordic hydro for balancing Northern-European wind power.

G. Portugal

In Portugal, two studies related to wind integration have been completed:

- Power system stability study of the Iberian network under the 2001/ 77 - EC Directive wind capacity goals;
- Assessment of the extra power reserves requirements under the 2001/ 77 - EC Directive wind capacity goals.

Ongoing activities include:

- definition of the wind energy sustainable potential and correlation with limited local transmission network capacity;
- study and planning of the grid integration of small wind parks (DGS operation) focusing on the rise of the voltage quality of weak radial rural distributions grids (started beginning 2006);
- planning and construction of new transmission grid reinforcement to accommodate 5000 MW of wind capacity is currently underway;
- Power system stability studies of the Iberian system in scenarios of large scale wind integration involving: development of fast dynamic security assessment tools, use of FACTS and special control mechanisms for wind generators;
- Evaluation of the adequacy of reserve amounts and types (including hydro pumping storage) in the Iberian system in scenarios having large scale integration of wind generation;
- Ancillary services delivery through wind generation;

- Impact on small signal stability from large scale integration of wind generation and identification of solutions for damping large oscillations;
- Correlation of Wind and Hydro Resources and Production and the impact of added storage;

H. Spain

In Spain, Universities, Research Institutes, Utilities and System Operators have performed Wind Integration studies [16]. A substantial body of the work focuses on power systems stability and wind power prediction tools to improve forecasting for electricity production.

Ongoing work on wind integration includes grid congestions management, grid reinforcement, power system stability analysis, forecast model improvement, wind farm control and wind power data analysis.

I. Sweden

A study of 4000 MW wind power in Sweden was published in 2005 [17].

The on-going PhD work at KTH are related to

- Wind power in areas with limited export capabilities: Which methods can be used within a deregulated framework to make hydro power owners interested in balancing wind power? How will uncertainty of wind speed forecasts affect the possibilities to balance wind power with hydro power? How can grid tariff construction affect the interest of hydro power owners? What are the possibilites to use pumped storage in the hydro system to balance wind power? Can grid extensions also be motivated by the interest to use hydro power as reserve power?
- Hydropower bidding model under significant uncertainty: Models are developed for how to bid power both on the day-ahead market and on the regulating market when the amount of uncertainties, caused by wind power, will increase.
- Frequency control in a system with large amounts of wind power: at which level of wind power it is necessary for the wind power to participate in the balancing. At KTH a model is developed that simulates in a comparatively detailed way how the TSO will keep the balance in the system with a larger share of wind power. The aim of the model is to minimize the imbalance costs for the TSO.

J. UK

Several studies quantifying the integration costs of wind power have been published in UK [18], [19], [20], [21]. UK has been very active in the following relevant topics:.

- Adequacy of network: transmission network planning and operation standards for systems with large contribution of wind generation and development of methodologies for their update
- Evaluation of contribution of wind power to generation security [22]
- Role and value of storage and demand side in managing intermittency [23]
- Role and value of wind forecasting
- Impact of wind turbine technology and control on network stability [24], [25]

K. USA

An increasing number of traditional utilities and system operators are performing operational impact studies: States of Minnesota [26], Wisconsin [27], Oregon-Wyoming [28], New York [29] and Colorado [30]. A summary of these can be found for example in IEEE [31].

Studies for Public Service of New Mexico and Sacramento Municipal Utility District have started, using AREVA dispatch simulator used for training utility operators which allows for simulation of the power system response to the variable wind energy generation and extreme events. Issues of accuracy of wind forecasting will be addressed. NREL is investigating the use of GE MARS, a model of the transmission system and wind plant locations, to address ability to move wind and power system reserves where they are needed.

Ongoing work includes also several systems with lots of multi-constrained hydro in the Northwest US and Western Area Power Administration (WAPA) system, including Bonneville Power Administration, Grant County Public Utility District on the mid-river section of the Columbia, Avista located in North Idaho and eastern Washington state, Idaho Power, central Idaho, Snake River and on the Missouri River (Dakotas). UWIG is participating in a project with Xcel Energy to investigate the incorporation of a range of wind plant output forecasts into utility operations planning tools.

Work for high penetration has just started in US, driven by RPS mandates and consideration of higher mandate levels. State of Minnesota, 20% by energy, will examine mitigation of wind through multiple means including wind curtailment, and changing the conventional generation mix regulation and ramping characteristics. Market provision of ancillary services will also be examined, as well as control area consolidation rather than individual utility and smaller control area mitigation. California Energy Commission/ISO, up to 15% renewables by capacity, will also examine mitigation and cost reduction potentials.

L. Other Studies

The participants of this task do not cover all countries, and studies on wind integration are made also by organisations, like the recent publications of EWEA Grid Report [32] and IEA Natural Variability report [33].

There is an ongoing activity at CIGRE under Study Committee SC C6 on distributed generation called Integration of large share of fluctuating generation, and under SC 1.3, on the subject of Power System Planning with the Uncertainty of Wind Generation.

New study by European TSOs is starting in 2006. The objective of the European Wind Integration Study (EWIS) is to seek proposals for a generic and harmonized European wide approach towards wind energy issues addressing operational and technical aspects including grid connection codes, market organizational arrangements, regulatory and market-related requirements, common public interest issues and even some political aspects impacting the integration of wind energy.

V. State-of-the-art of Power System Impacts: Reviewing Studies Made So Far

A wide range of case studies from different power systems that have already been made will be analysed. A state-of-the-art report will be made during 2006, summarising results and reviewing methodologies, tools and data used in studies made so far on power system impacts of wind power. Explaining factors for different results will be sought:

- Wind penetration levels (with and without interconnection possibilities);
- How large is the system area? How geographically dispersed is wind power production?
- Power system operational characteristics of the installed generation plants, inherent variability of system load, the network topology as well as the rules and strategies practised in relation to transmission capacity and treatment of imbalances;
- What has been taken into account? How conservative are estimates?

Also the representation of the results of the studies is important when making comparisons: both the terms and the metrics used in the power systems and in representing the results vary:

- How wind power penetration is defined: relative to installed generation capacity, consumed energy, min load + interconnector capacity
- Reserves: time scales for primary /secondary reserves, division to disturbance /operational reserves, time scales for determining imbalances taken care by the reserves: operational hour or forecast errors day-ahead or intraday
- Integration cost, avoided cost, compared to what: integration cost of other production forms? market versus technical cost, social cost?

First ideas on what are important factors to take into account when estimating integration costs will be stated in the report. An effort to draw conclusions on the range of power system impacts of wind power and costs of wind power integration will be made in further work of the task.

VI. Conclusions

There are a multitude of studies made and ongoing related to cost of wind integration, however, the results are not easy to compare. To draw conclusions on the range of impacts and costs international cooperation is needed. An international forum for exchange of knowledge of power system impacts of wind power has been formed under IEA Implementing agreement on Wind energy. Task “Design and Operation of Power Systems with Large Amounts of Wind Power” will analyse existing case studies from different power systems. The task will collect and share information on the experience gained and the studies made, and review methodologies, tools and data used. An effort to draw conclusions on the range of power system impacts of wind power and costs of wind power integration will be made. The outcome will be guidelines on methodologies.

An in-depth review of the studies is needed to draw conclusions on the range of integration costs for wind power. State-of-the art review process will seek for reasons behind the wide range of results for costs of wind integration – definitions for wind penetration, reserves and costs; different power system and load characteristics and operational rules; underlying assumptions on variability of wind etc.

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