

## 1 Introduction

Based upon the results of the IEA Topical Expert Meeting #44 on the Integration of Wind Systems a new R&D Task on the “Design and Operation of Power Systems with Large Amounts of Wind Power” will be formed within the “IEA Implementing Agreement on the Co-operation in the Research, Development and Deployment of Wind Turbine Systems”.

### Background and previous work

At the beginning of 2005, there were 48 GW installed worldwide increasing by 8 GW per year. Of this wind generating capacity, more than 70 % is installed in Europe, more than 15 % in North America and 10 % in Asia. Due to its decreasing and competitive costs coupled with the fact that it is a clean energy resource, wind energy capacity is likely to continue to grow rapidly over the next two decades.

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. Wind power generation represents only 1–2 % of the total electricity consumption in the Nordic power system (Nordel) or the Central European system (UCTE). The penetration levels in the US regional systems are even lower. However, already some areas/regions (e.g. West Denmark, North of Germany and Galicia in Spain) show a high penetration. The existing targets for wind power anticipate a quite high penetration of wind power in many countries.

In recent years, several reports have been published in many countries investigating the power system impacts of wind power<sup>1</sup>. International collaboration is also going on in CIGRE, EU, UWIG and other IEA Wind Tasks<sup>2</sup>.

### Challenges to be met

Maximising the energy and emission savings that can be delivered by wind power in a power system are issues of great relevance for many countries in the IEA R&D Wind Implementing Agreement. 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. Case studies that analyse the feasibility, benefits, detriments, and costs of wind integration will likely be the mechanism through which the feasibility of wind power integration is demonstrated. As general 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.

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<sup>1</sup> for example the following references: 1) Smith, J. C., DeMeo, E. A., Parsons, B., Milligan, M. 2004. Wind power impacts on electric power system operating costs: summary and perspective on work to date. Global Wind Power conference GWPC'04, April 2004, Chicago, USA; 2) Dale, L., Milborrow, D., Slark, R., Strbac, G. 2004. Total cost estimates for large-scale wind scenarios in UK. Energy Policy 32, pp. 1949–1956; 3) Holttinen, H. 2004. The impact of large scale wind power production on the Nordic electricity system. VTT Publications 554. Available at <http://www.vtt.fi/inf/pdf/publications/2004/> ; 4) “Planning of the Grid Integration of Wind Energy in Germany Onshore and Off shore up to the year 2020 (dena Grid study)”, English summary available from [www.dena.de](http://www.dena.de)

<sup>2</sup> CIGRE (International Council on Large Electric Systems) has Study Committee SC C6 on distributed generation. UWIG (Utility Wind Integration Group) is working in the US <http://www.uwig.org>. EU is starting Technology Platforms, f.ex. on Smart Electricity Networks.

Wind power will introduce 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 other hand on how much wind power there is (the portion of consumption covered by wind power production) and on the other hand how much flexibility there exists in the power system. Power systems worldwide are quite different in what concerns the basic operative parameters: the operational characteristics of the installed generation plant, inherent variability of system load, the rules and strategies practised in relation to transmission capacity and treatment of imbalances and the network topology (well meshed versus radial grids). To assess the impacts of wind power it is relevant to know how the wind power is geographically dispersed, to account for the smoothing of variations. The flexibility of the power system and how much this flexibility can be increased cost effectively is as important as the assessment of grid reinforcement externalities.

Although specific approaches to grid integration of wind projects may differ substantially from country to country, it is important to highlight that there are even more characteristics common to all of them. Thus, there may be significant advantages in forming an international collaboration network designed to share information, analyse techniques and case study results. Through international collaboration, best practises in system impact studies for wind power can be formulated and this gives valuable input to determining the integration costs and acceptable wind power penetration levels in different countries.

## 2 Objectives

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 participants in the Task will conduct co-operative research on power system operation with large amounts of wind power. The participants will collect and share information on the experience gained and the studies made up to and during the task, with analyses of and guidelines on methodologies used to determine the impact of wind power on power systems. The main emphasis is on the technical operation: the impact that wind power has on reliability and on efficiency of the power system. Costs will be assessed when necessary as a basis for comparison.

Specific or partial objectives are:

- Establishment of an international forum for exchange of knowledge and experiences related to power system operation with large amounts of wind power. Create coherence between parallel activities (EWEA/AWEA, UWIG, ETSO, CIGRE, UCTE, national efforts);
- Produce a state-of-the-art report on the knowledge and results so far on system operation with wind power, including a list of studies and on-line library of reports/articles;
- Analyse the most relevant wind power grid integration studies that have been made so far, review methodologies and input data, and make a summary on the range of wind power impacts and costs for different power systems;
- Contribute to technology mitigating and lowering unfavourable impact of wind power and to concepts supporting enhanced penetration of wind power: modification of wind farm controls and operating procedures; dynamic line ratings; storage; demand side

management DSM. The ultimate ambition here is to contribute to maturity and commercial application of innovative concepts by communicating success stories.

- Develop guidelines on the recommended methodologies when estimating the impacts of wind power on power system reliability and efficiency, and further, the costs of wind power integration;
- Evaluate current system operation practices and planning methodologies with respect to how appropriate they are for use in systems with high wind penetration. Review the modifications to these that have been necessary in jurisdictions that have high wind penetration with a view to developing best practice recommendations;

The common international challenge is to adapt the existing power systems to enable a substantial increase of wind penetration in a time frame considerably shorter than the lifetime of the assets, like up to year 2020, and at economically feasible costs.

### 3 Means to achieve objectives

The participating countries will perform case studies, and analyse existing studies, on system operation and planning with large amounts of wind power. System operation issues are addressed both in small systems, like Ireland, and in larger interconnected systems, like the Nordic system able to trade reserves between countries. The case studies will address different aspects of power system efficiency and reliability<sup>3</sup> (Figure 1).

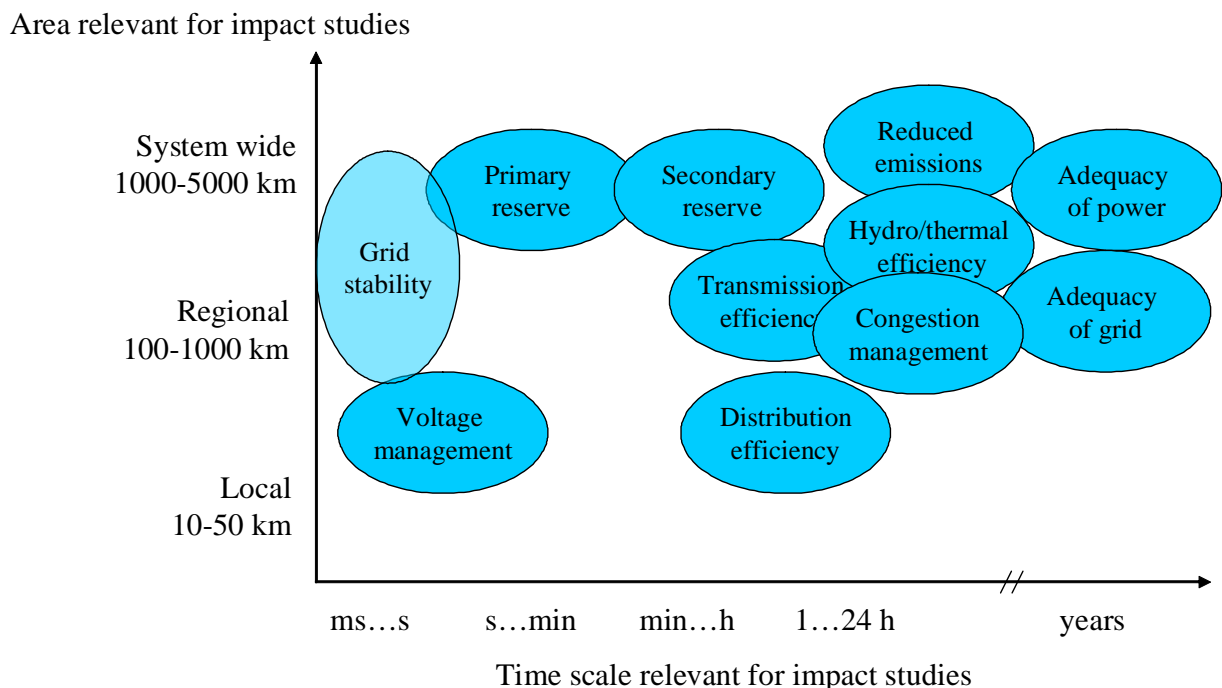


Figure 1. Impacts of wind power on power systems, divided in different time scales and width of area relevant for the studies.

<sup>3</sup> 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 analysed and made during this annex thus fall into following subtasks:

**A) Balancing** (divided to time scales regulation/load following/unit commitment):

Both security of supply issues (reserves) and the overall efficiency of production in the energy system are addressed here. Results from Annex XXIV Wind&Hydro are relevant in this subtask. Also mitigation measures like DSM and storage as well as wind farm controls are relevant here, as they increase the flexibility of the power system and lower the negative impacts of wind power.

*Regulation and load following time scales:* cost of reserve/regulating power (time-scale minute...half an hour).

The key question is how the amount of reserves is planned for in the power system and how the uncertainty introduced by wind power will affect this. 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 be made, depending on region size relevant for balancing, initial load variations and how concentrated/distributed wind power is sited. The technical reserve requirement is assessed, but also increase in costs will be an issue. The costs will depend on the marginal costs for providing regulation or mitigation methods used in the power system.

*Unit commitment time scale:* 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, not taking into account wind power uncertainties in a most correct way and sometimes ignoring existing flexibilities in the system. Analysing and developing methods of incorporating wind power into these models is important. The model 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 also in cases when the system imbalance is not affected. Analyses on how current market mechanisms affect wind power producers will be made and this can result in recommendation on ideal market mechanisms that penalise wind power production in a way that follow the real costs incurred to the power system.

**B) Adequacy of power:** Total supply available during peak load situations.

The reliability of the power systems 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 and a consensus on this aspect would be desirable.

### **C) Grid:**

In this annex local issues of grid connection like power quality are not addressed but the more system related issues described below.

With large amounts of wind power the adequacy of grid has to be addressed. This means assessment of grid reinforcement within regional and in case of large offshore wind farms even national development planning. On the other hand maximum use of existing investments is of primary interest for network operators. Alternatives to new power line investments are important: 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.

The impacts of wind power to the transmission and distribution grid 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. Data is needed to estimate the instantaneous maximum wind energy production within a region or country as well as the maximum wind power production/minimum load ratio and the frequency of critical congestion situations.

At some penetration wind power starts to affect system stability. 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.

Grid integration interests of the Offshore Annex XXIII are of relevance in this subtask. The partners will use models that have been validated by the Annex XXI Dynamic models of wind farms for power system studies.

In all subtasks, the objectives of the annex should be considered: to exchange knowledge, consider in detail the input wind power data and analyse assessment methodologies and also cost allocation impacts when necessary (Table 1). Basic definition for “high penetration” should be made, at least tentatively, as the ambition associated with this term is differing from one participating country to the other. High wind power penetration can be for example 10–20 % of yearly electricity consumption. How wind power penetration should be defined: relative to installed generation capacity, consumed energy, interconnection capacity etc.

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 which 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. The annex will therefore examine the effectiveness of various system assessment methodologies (for system security, adequacy, etc) applied to systems with high wind penetration. The aim is to arrive at methodologies that treat wind power as objectively as possible. Should there arise needs to modify the present methodologies, exchange of ideas and collaboration with the power system Transmission System Operators (TSO's) will be requested to achieve practical and useful guidelines and tools.

Increased requirements due to wind power can be seen as extra energy/capacity needed in the system. The cost estimates should be defined as actual (physical) costs rather than how costs are implemented (market cost). Other power plants have similar externalities, and common standard methods to internalise these costs, or a base cost with which wind power costs are compared with should be defined, if possible. The economic limits on wind penetration will depend upon how costs are allocated within a market. Guidelines will describe the respective national market mechanisms and their impact on cost allocation. Also ideal market mechanisms, where the costs imposed on the producers reflect the true system costs may be suggested if considered appropriate.

The operating agent shall see that the work is coordinated between the other Annexes in IEA IA Wind, to avoid double work. The main results of *Annex XXIV Integration of Wind and Hydropower Systems* and the grid integration interests of *Annex XXIII Offshore Wind Energy Technology Development* are taken as examples in this Annex. In Offshore task the main emphasis is in more local grid issues and specific offshore questions, whereas in this task only the examples that affect the whole system are taken.

## 4 Results expected

State-of-the art and guidelines with list of best practices (methodology, input data, especially how wind data is to be used in studies) are results from all subtasks. The annex shall come up with quantification of the range of impacts and costs (at least indicatively) for different power systems, relative to system size and structure, wind power dispersion, amount of flexibility. Rules of thumb that could be used as first step when considering large penetration of wind power in power systems will be drawn, when possible.

The results of the Annex will be published in reports and available on a server:

- Proceedings from workshops (presentations given at research meetings plus notes of the summary discussions)
- Creation of an on-line library composed of case study reports generated by the research participants.
- Due to the expected relevance of the outcomes of this Annex to the system operation of the different countries, results on guidelines, new methodologies and best practises will

be available to the TSO's of all participating countries, when not directly represented in the Annex.

## **5 Time Schedule**

The Annex was approved by the IEA IA R,D&D ExCo in September, in Lucerne, Switzerland. It will continue for a period of three years beginning in 2006 and ending at the end of 2008 or resumed at an earlier date, if the Agreement expires or is terminated.

## **6 Operating Agent**

The Technical Research Centre of Finland VTT is designated as Operating Agent.