Integrating Wind

Developing Europe's power market for the large-scale integration of wind power

Executive Summary

PRINCIPAL AUTHOR:
Frans Van Hulle, Technical advisor to the European Wind Energy Association (EWEA)

AUTHORS:
John Olav Tande, Sintef Energiforskning AS
Kjetil Uhlen, Sintef Energiforskning AS
Leif Warland, Sintef Energiforskning AS
Magnus Korpås, Sintef Energiforskning AS

Peter Meibom, Risø– DTU
Poul Sørensen, Risø– DTU
Poul Erik Morthorst, Risø– DTU
Nicolaos Cutululis, Risø– DTU
Gregor Giebel, Risø– DTU
Helge Larsen, Risø– DTU

Achim Woyte, 3E
Geert Dooms, 3E
Pierre-Antoine Mali, 3E
Alexandre Delwart, Windtest (formerly 3E)

Frits Verheij, Kema Nederland BV
Chris Kleinschmidt, Kema Nederland BV
Natalia Moldovan, Kema Nederland BV

Hannele Holttinen, Technical Research Centre of Finland (VTT)
Bettina Lemström, Technical Research Centre of Finland (VTT)
Sanna Uski-Joutsenvuo, Technical Research Centre of Finland (VTT)

Paul Gardner, Garrad Hassan and Partners Ltd
Greg van der Toorn, Garrad Hassan and Partners Ltd
James McLean, Garrad Hassan and Partners Ltd
Simon Cox, Garrad Hassan and Partners Ltd

Konrad Purchala, Tractebel Engineering
Sebastien Wagemans, Tractebel Engineering

Albrecht Tiedemann, Deutsche Energie-Agentur (dena)
Paul Kreutzkamp, Deutsche Energie-Agentur (dena)
Chanthira Srikandam, Deutsche Energie-Agentur (dena)
Jakob Völker, Deutsche Energie-Agentur (dena)

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FOREWORD

In 2008, more new wind energy capacity was installed in Europe than any other power generating technology, reaching a cumulative total of 64 GW. This demonstrates the growing recognition that wind energy is a low-risk, future-proof investment that creates jobs, generates technological leadership, enables greater energy independence and helps protect the climate. The Renewable Energy Directive, agreed in December 2008, establishes a 20% renewable energy target by 2020 for Europe, and the European Commission has suggested that 12% of the EU electricity demand needs to come from wind to meet this target, up from 4% in 2008.

However as the amount of wind energy in the electricity grid increases, new challenges emerge. Initially built for traditional power sources, the grid is not yet fully adapted to the foreseen levels of wind energy, and nor are the ways in which it is designed and operated. So far, adaptation has been slowed by planning and administrative barriers, lack of public acceptance, insufficient economic incentives for network operators and investors to undertake transmission projects of European interest, and a generally fragmented approach by the main stakeholders.

European grids need to be reinforced and better interconnected for higher system security and a more economical dispatch of power that ensures low wholesale electricity prices EU-wide. Moreover, when a greater amount of wind is added to the mix, the grid also needs to be able to guarantee an efficient transportation and exchange of power across national borders, so that the wind blowing in one spot, however remote or far offshore, can provide power far and wide. Grid reinforcement and an adapted power market design are essential if the EU's 2020 targets are to be met and surpassed.

The TradeWind project is the first EU-level study to explore the benefits a European grid with better interconnections and an improved power market design can have on the integration of large amounts of wind power. This report presents the project's findings. Looking ahead as far as 2030, it provides recommendations and guidelines for action at EU and national level to move towards a single European grid and power market that will enable more European citizens to benefit from wind power.

Arthorous Zervos
President, European Wind Energy Association

Frans Van Hulle
TradeWind Technical Project Coordinator

Source: EWEA / Winter

Executive Summary

Introduction

Europe's dependency on imported fossil fuel has become a threat to economic stability, increasing uncertainties over energy prices. At the same time, the European electricity industry is facing a huge challenge related to generation capacity investment needed in the coming years. The surplus capacity that existed in some countries prior to liberalisation is diminishing, and many existing power plants are getting closer to their decommissioning dates. For these reasons, one of the key points on the European energy policy agenda is to increase the share of the demand that is covered from renewable energy sources. European Commission targets related to reduction of greenhouse gases and energy dependency state that by 2020, 20% of all energy demand will be covered by renewables. The Commission estimates that approximately 34% of EU's electricity demand needs to come from renewables by 2020 (up from 16% in 2006) to meet the overall energy objective. It also envisages that wind energy will meet 12% of EU electricity demand by 2020, up from approximately 4% in 2008.

The renewable source of energy with the most potential for helping meet these targets is wind power. It is a very promising and mature renewable technology, using resources that are favourably distributed between Member States, both onshore and offshore. It is not only able to contribute to European energy independence and meeting the future climate goals, but it could also help to turn the serious energy security problem into a new opportunity for Europe providing economic benefit, employment, technology and research leadership.

The recent rapid growth in wind power generation, triggered by technological and industrial development and the move towards sustainable economics, indicates that wind power should be seen as one of the main domestic sources for electricity generation in the EU. However, with ever-increasing amounts of wind energy in the system, new challenges arise for the functioning of the interconnected grid, especially for balancing, security, planning, cross-border transmission and market design.

For an economic and efficient integration of large amounts of a variable output source like wind power, changes must be made to the design and operation of the power system for generation, transmission and distribution. When envisaging penetration levels of 20% of gross electric demand or more from wind energy, new directions need to be followed for both the design and operation of the power system and the electricity markets. Hence it is critical that the decision-making processes – for example, on grid reinforcements, technical standards, market rules and so on – are well thought through, resulting in consistent policy decisions.

Based on a single European grid and power market system, the TradeWind project explores to what extent large-scale wind power integration challenges could be addressed by reinforcing interconnections between Member States in Europe. Additionally, the project looks at the conditions required for a sound power market design that ensures a cost-effective integration of wind power at EU level.

In this way, the study addresses two issues of key importance for the future integration of renewable energy, namely the weak interconnectivity levels between control zones and the inflexibility and fragmented nature of the European power market. Work on critical transmission paths and interconnectors is slow for a variety of reasons including planning and administrative barriers, lack of public acceptance, insufficient economic incentives for TSOs, and the lack of a joint European approach by the key stakeholders.

At EU level, there are various political processes ongoing that involve grid improvements, such as the Third Liberalisation Package,[a] the Strategic Energy Technology Review,[b] the Commission Green Paper on European Energy Networks,[c] the development of a Blueprint for a North Sea offshore grid and the Priority Interconnection Plan.[d] Within these processes, the concept of a truly European transmission network and an efficient European power market that integrates large amounts of renewable energy needs to be backed up with recommendations based on technical and economic analysis – this is where TradeWind intends to contribute.

In order to analyse interconnection and power market rules in Europe, TradeWind simulated the power flow in the EU high voltage grid with a simplified DC flow based market model, representing the European power system as a single, perfectly functioning market. Development scenarios of distributed wind power capacity have been assumed – anchored at the years 2010, 2015, 2020 and 2030.

A Europe-wide wind model was used to look into the effects of possible grid dimensioning situations due to meteorological events, such as the passing of deep low pressure systems which are expected to cause large variations in wind power production and hence measurable changes in cross border flow. In parallel, main transmission bottlenecks have been identified, suggesting the most obvious network upgrades that would relieve existing structural congestion. The methodology allowed for the associated implementation costs as well as the effect on power flow to be quantified.

Equivalent network representations were used for the different synchronous zones: UCTE (all of Europe except the Nordic countries, GB and Ireland), Nordel (the Nordic countries), and GB and Ireland. Due to the limited amount of data the TradeWind Consortium had access to, especially for the UCTE area, intra-zonal transmission constraints were taken into account only to a limited extent, restricting cross-border flow mainly by individual tie-line capacities and net transfer capacity (NTC) values. To provide a degree of validation, the simulation results were compared with current

[a] Commission of the European Communities, 2007.
Energising Europe – a real market with secure supply (third legislative package). Available at http://ec.europa.eu/energy/gas_electricity/third_legislative_package_en.htm

[b] Commission of the European Communities, 2008. Second Strategic Energy Review - Securing our Energy Future.
Available at http://ec.europa.eu/energy/strategies/2008/2008_11_ser2_en.htm

[c] Commission of the European Communities, 2008.
Green Paper: Towards a Secure, Sustainable and Competitive European Energy Network. COM (2008)782.

[d] Commission of the European Communities, 2006.
Communication from the Commission to the Council and the European Parliament: Priority Interconnection Plan. COM (2006) 846.


Source: EWEA/Faulkner

cross-border exchanges and results from a more detailed recently obtained model, strengthening the confidence of the TradeWind Consortium in the results and conclusions drawn. The intention was not to make an in-depth grid dimensioning study nor to consider dynamic grid behaviour and reliability aspects such as N-1 considerations.

Beside the Europe-wide assessment of the transmission networks, TradeWind analysed the power market's efficiency in handling large amounts of wind power. For this purpose, two simulation tools – namely, PROSYM and the WILMAR Planning Tool – were used to analyse a number of fundamental scenarios defined by the installed wind power capacity, the electricity demand and the energy economic scenario for a given target year. The considered parameters are interconnector capacity values (NTC), market gate closure time (or deadline for rescheduling of dispatch decisions) and the extension of the overall market area. The TradeWind cost analysis focuses on the marginal operation costs and does not take into account investment costs, additional balancing costs and wind energy incentive schemes. The cost analysis should be considered in this perspective.

Main conclusions of the TradeWind study

TradeWind was the first study to look into large-scale cross-border wind power transmission and market design at European level. From the simulations and analysis performed, it draws the following conclusions.

IMPACTS OF INCREASING WIND POWER ON CROSS-BORDER POWER FLOWS

Increasing wind power capacity in Europe will inevitably lead to increased cross-border energy exchanges. This implies that the current cross-border transmission bottlenecks will get more severe. Especially with the amounts of wind power capacity expected in 2020 and 2030, congestion can be expected to increase on the borders of France, between GB and Ireland and on some of the Swedish, German and Greek borders. The fact that wind power cannot be predicted with 100% accuracy leads to deviations between the expected and actual cross-border power flows on most interconnectors during a substantial part of the time, and this will further exacerbate the congestions.

The economic consequence of these transmission constraints is restricted access to cheaper generation resources (such as wind power which has zero marginal production costs because the fuel is free) and consequently higher electricity prices. The diminishing transmission capacity margins can also lead to reliability issues. As such analysis is out of the scope of the project it has not been carried out by the TradeWind partners.

As far as meteorological events are concerned, cross-border transmission is not significantly affected by wind power fluctuations for most of the European countries for installed wind capacity scenarios up to 2015. Even if wind power plants are cut off due to a rare storm and a dramatic drop of production occurs in one country, the effect was not so much seen at a European scale. However, the TradeWind Consortium suggests that this issue be studied more closely with more precise and higher resolution wind data, especially at wind penetration levels of 10% and more. Due to its limited temporal resolution, the wind data used in the TradeWind project can lead to short-term local wind power variations being underestimated.

NECESSITY OF TRANSMISSION UPGRADE ONSHORE AND OFFSHORE

It is clear that the future transmission reinforcements currently planned by TSOs plans are insufficient to prevent bottlenecks being aggravated and to alleviate congestion. As a consequence, without transmission upgrades beyond those currently planned, even a moderate increase in wind capacity will cause unnecessarily high operational costs of power generation in 2020 and 2030.

Both wind energy and transmission system upgrades contribute to reducing these operational costs of power generation. It is therefore important to consider the combined benefits when investment costs together with additional costs for balancing, incentives and the like are brought to the picture.

TradeWind has identified 42 onshore interconnectors and a corresponding time schedule for upgrading that would benefit the European power system and its ability to integrate wind power. Reinforcing these lines should lead to substantial cost savings for power system operation. Especially for 2020 and 2030, the benefits of these transmission upgrades become significant and amount to savings in total system operation costs of 1,500 M€/year, justifying investments in the order of €20 billion.


Source: Iberdrola

An interlinked (meshed) offshore grid could link future offshore wind farms in the North Sea and the Baltic Sea and the onshore transmission grid. A preliminary economic analysis based on an installed wind power capacity of 120 GW shows this system compares favourably to a radial connection solution where wind plants are only connected directly to the onshore grid. Among the possible benefits are increased cable utilisation, better access to the flexible hydro capacity of Norway, greater flexibility for transporting offshore wind power to areas of high prices and improved power trade between Sweden, east Denmark and Germany. It is recommended to take account of necessary onshore reinforcements in a further analysis. This could not be done in the TradeWind project because of the limitations of the available network data.

In order to effectively integrate high amounts of offshore wind into the power system, it is necessary to further upgrade the onshore network. Highly congested mainland connections were observed internally in Germany and Sweden, and in interconnectors between Belgium and the Netherlands and between Belgium and France. In addition to further reinforcements of mainland connections in these areas beyond 2015, much stronger offshore "super" grids with direct extensions towards major load centres inland could be built. Such a supergrid should not be a substitute for the necessary reinforcements of the onshore grid that are in the pipeline or under construction.

Taking into account the reluctance among the stakeholders and the general public, and the long implementation periods normally associated with the reinforcement of transmission systems, it is important to utilise existing transmission lines to the maximum extent by implementing power flow control technologies.

The investments are largely to be made in the individual Member States for both wind energy and transmission. This makes it difficult for transmission system companies to identify profitable transmission development projects, especially cross-border projects. The European dimension of these transmission justifies an EU approach to developing financing schemes for pan-European transmission grid reinforcements. In parallel there is a pressing need for harmonised planning and authorisation processes (fully supporting the TEN-E and related processes).

EU-WIDE WIND POWER CONTRIBUTION TO SYSTEM ADEQUACY

As well as providing large amounts of electricity that would otherwise be generated by fuel-burning plants, wind power offers a high degree of reliability. Joining together, or 'aggregating' wind energy production from several countries strongly increases wind power's contribution to firm power capacity in the system. The larger the geographical area represented by the grouped countries, the higher the increase of the capacity credit. For 2020 and 200 GW of installed wind power capacity, the effect of aggregating wind energy across multiple countries almost doubles the average capacity credit compared with the capacity credit averaged over separate countries. With the probabilistic method, the capacity credit for 200 GW wind power rises to a level of 14% which corresponds approximately to 27 GW of firm generation capacity. Providing sufficient transmission capacity between Member States will help maximise this effect.


Source: Nordex

POWER MARKET DESIGN FOR HIGHER MARKET EFFICIENCY

The establishment of intra-day markets for cross-border trade is of key importance for market efficiency in Europe. Allowing for intra-day rescheduling of cross-border exchange will lead to savings in operational costs in the order of €1-2 billion per year compared to a situation where cross-border exchange must be scheduled day ahead. In order to ensure efficient interconnector allocation, they should be allocated directly to the market via implicit auction.

Intra-day rescheduling of the portfolio - that is, taking into account wind power forecasts up to three hours before delivery - results in a reduction in operational costs of power generation of €260 million per year (compared to day-ahead scheduling) thanks to the decrease in demand for additional system reserves. This cost reduction assumes a perfect market and would be higher under the current, distorted market conditions.

The European electricity market needs the following major design characteristics in order to enable effective and efficient wind power integration:

- Features for intra-day rescheduling of generators and trade on an international level for low system costs and stable prices
- Wide-spread application of implicit auctioning to allocate cross-border capacity (i.e. market coupling, market splitting and so on)
- The availability of sufficient interconnection capacity, especially after 2015

Recommendations of the TradeWind study

Based on the analysis of the simulation results, TradeWind has developed a series of recommendations. These are addressed to policy makers, TSOs, energy regulators, wind power producers and traders. The recommendations relate to:

- Necessary technical developments
- European-wide transmission planning
- Regulation in the electricity market
- National and EU policies
- Further studies

Most of the recommendations are valid for the short to medium term.

UPGRADING AND OPERATING THE TRANSMISSION NETWORK

The staged network reinforcements as considered by TradeWind should be further investigated and promoted as a priority because of expected increase in wind generation after 2015. Network planning and other measures should aim to relieve the expected congestions in 2020 and beyond due to a higher demand and installed wind power capacity. The most severe bottlenecks are expected to be located on borders between France and its neighbours (Spain, Switzerland, Belgium, GB); between GB and Ireland; between Germany and Sweden; between Sweden, Poland and Finland, and between Greece and Bulgaria.

The TradeWind study should be followed up with more detailed design and optimisation of offshore grid solutions. The initial assessment in TradeWind indicated that meshed offshore grids are the economically optimum means of interconnection and that HVDC meshed grid technologies would offer important advantages for this application. Therefore it is recommended that R&D efforts in meshed HVDC technologies are sped up to enable them to be implemented for network expansion in the North Sea. The TradeWind HVDC meshed grids are proposed for consideration as a basis for developing the EU Blueprint for an offshore North Sea Grid.

In order to effectively integrate high amounts of offshore wind into the power system, it is also necessary to further upgrade the onshore network. Highly congested mainland connections were observed internally in Germany and Sweden, and on interconnections between Belgium and the Netherlands and Belgium and France. In addition to further reinforcements of mainland connections in these areas beyond 2015 should be considered building much stronger offshore grids with direct extensions towards major load centres inland.

A very important conclusion of TradeWind analyses is that there is almost the same need for transmission system upgrades if very little new wind power capacity is installed. Even if we were not going to increase wind power substantially, European consumers would benefit economically from the upgrades and operational changes suggested here. Both wind energy and transmission system upgrades contribute to reducing these operational costs of the power system. It is therefore important to consider the combined benefits when investment costs and other additional costs related to wind power are assessed.


Source: Vestas

Financing schemes for pan-European transmission grid reinforcements should be developed at EU level, as well as harmonised planning (including spatial planning) and authorisation processes fully supporting the TEN-E and related processes.

Strategies for handling regional concentration of wind energy and moving storm fronts should be developed further in order to avoid any negative impact on the security of the system as a whole. These strategies should include a more intensive use of wind forecasting and the possibility for system operators to control wind generation in a critical situation where strictly necessary for safe system operation. In this way, they could reduce the rapid loss of wind generation caused by storm fronts to a more manageable gradient by reducing wind production in advance of the storm front.

Contractual arrangements ('grid codes', connection agreements and similar) should contain provisions for wind generation to be controlled by the system operator as this may in some circumstances be the best solution to specific problems. The means of allocating curtailment, and any compensation arrangements, should be transparent and equitable between different generating technologies.

All grid operators should have 'visibility' of the real-time output of all types of generation connected to their networks. Additionally, at least the summated output of generators connected to distribution systems operating below the transmission system operator (TSO) grid should be available for the TSOs (except perhaps the smallest generators connected at domestic level). The associated cost – for example, for communications and control methods - is small in comparison to the benefits that could be provided to system operators.

POWER MARKET DESIGN

The design of the power market should allow intra-day rescheduling of international transmission lines. The establishment of cross-border intra-day markets is of key importance for market efficiency in Europe.

Further, to maximise the economic benefits from interconnections, the market's capacities should be allocated via implicit auctions, for example market coupling or splitting algorithms. Optimally, these algorithms should be flow based. Further market integration in Europe – such as the regional market initiatives – should be pursued.

Power systems with wind energy penetration levels of 10-12% of gross electricity demand need, beside more flexible plants, also the slower power plants (with start-up times of above one hour) to participate in the intra-day rescheduling.

An international exchange of reserves brings further advantages. The trade-off between savings in investments for flexible power plants and sharing of reserves across borders should be investigated with dedicated models.

WIND POWER GENERATION

For the large-scale deployment of offshore wind, the siting process should ensure as much geographical spreading as possible in order to minimise large wind power variations. For the same reason, offshore wind farms in large-scale deployment should be connected to meshed offshore grids, possibly with controllable power flow, rather than to single radial connections from individual wind farms to the shore.

The options of active wind power plant control should be further explored, both from a technical and a commercial point of view. In some load situations, such as low demand combined with high wind speeds, some of the wind power capacity might be more useful as a reserve than as realised generation, making use of current state-of-the art wind power plant controllers that enable the use of the wind power as reserve.

As long as the power market is operating differently from a perfect market, because of the constraints in cross border exchange amongst other reasons, priority access and dispatch for wind power should be regarded as a means of helping keep wholesale power prices low and meeting the European 20-20-20 targets.

OTHER FORMS OF POWER GENERATION

Wind power capacity credit should be assessed in TSO system planning (such as system adequacy forecast) in larger areas than a single country or balancing area, because its value increases with the size of the area. The methodology for estimating the capacity credit of wind power should be further developed and harmonised over Europe for use in system adequacy planning.

Energy efficiency measures in order to significantly reduce electricity demand are an essential complement to renewable energy, in order to prevent increase in demand offsetting the cost and CO_2 savings achievable through large-scale wind power.

The effect of demand-side measures such as electrical vehicles, cold storage, heat system integration and so on should be further investigated because of the expected system cost reductions in future systems with large-scale wind power. Moreover energy storage can help to avoid curtailment of wind power in situations of low demand combined with high wind energy generation.

Source: EWEA/Bris


Source: LM Glasfiber

EUROPEAN POWER SYSTEM STUDIES

For any further transmission studies on a European scale, the wind data developed for TradeWind can be used (geographically and time consistent set, with a temporal resolution of six hours). Linear interpolation of the six-hourly data into hourly values showed a high correlation with hourly measured data during validation checks of specific locations. It was possible to transform these data into hourly data by adding the hourly variability as found in historical hourly wind power series for use in the market models.

However, for studies of generation adequacy, balancing and similar issues, European wind data with better temporal resolution, ideally hourly, is recommended. Intervals shorter than this are not justified because the spatial averaging effect over large areas will have very little change on this sort of timescale.

The following parts of TradeWind's simulation toolbox should be further developed if used in European power system studies:

- Hourly measured wind data series
- More detailed data on conventional power generation
- The effect of energy efficiency measures and demand-side management on the integration of wind energy should be studied with more power demand scenarios
- More detailed geographical modelling of wind power capacities
- The effect of weather systems should be studied for higher wind power penetration levels and with more accurate data with higher resolution for short-term studies (say up to five years ahead): beyond that timescale, the uncertainties in wind generation installation rates and locations make more detailed geographical resolution unjustifiable
- Simulate the operation of power flow control options in the power system simulation tool to study possible related market benefits
- Further development and harmonisation of the methodology for wind power capacity credit estimation

In order to facilitate Europe-wide transmission studies, data on European networks for power system studies should be made more readily available.

TradeWind

TradeWind is a European project funded under the EU's Intelligent Energy-Europe Programme. The project addresses one of the most challenging issues facing wind energy today: its maximal and reliable integration in the Trans-European power markets. Recent studies show that a large contribution from wind energy to European power generation is technically and economically feasible in the same order of magnitude as individual contributions form conventional technologies, with a high degree of system security and modest additional costs. Wind power penetration is not constrained by technical problems with wind power technology, but by regulatory, institutional and market barriers.

TradeWind aims at facilitating the dismantling of barriers to the large-scale integration of wind energy in European power systems, on transnational and European levels, and to formulate recommendations for policy development, market rules and interconnector allocation methods to support wind power integration.

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