EN/02

WindBalance - Results

Balancing wind energy in the grid: an overall, techno-economic and coordinated approach

DURATION OF THE PROJECT
15/12/2006 - 31/01/2011

BUDGET
789.067 €

KEYWORDS
Balancing, grid integration, market integration, wind energy.

CONTEXT

As part of the European energy policy goals of sustainability, security of supply and improved competitiveness, the share of Renewable Energy Sources for Electricity (RES-E) is rapidly increasing. The Belgian national renewable energy action plan to comply with the EC renewable energy directive (2009/28/EC) estimates the installed capacity of wind power at 4320 MW towards 2020. This is expected to account for a yearly generation of 10.5 TWh, being 9% of the reference electricity demand scenario for 2020.

OBJECTIVES

The general objective of this project is to study the potential for massive wind integration in Belgium. Technical, economic and regulatory boundaries for a reliable and efficient integration in the power system are identified, together with necessary measures to transcend them.

CONCLUSIONS

Phase 1: market value of wind power

In the first phase of the project, a market simulator is developed to determine the costs and revenues for a wind power generator. This simulator serves as a tool to calculate market value that wind power yields in different markets under different market conditions and depending on the predictability of wind power output. The developed market simulator calculates the value of wind energy when traded on the local power exchange, i.e. Belpex Day-Ahead Market. Real-time, wind power prediction errors are settled with the imbalance tariffs imposed by the TSO. Abstraction is made from the additional revenues from green certificates which are currently settled at minimum prices between 90 – 107 €/MWh. The value of wind is expressed as the “Fixed Price OTC Equivalent” and is compared to the fixed price negotiated in Over-The-Counter (OTC) contracts.

This simulator is therefore a valuable support for valuating wind power investments or negotiating OTC-contracts. Moreover, the tool provides a base of an objective analysis of the real market value of wind energy under different market conditions and is therefore also a valuable tool for policy making.

The simulator is validated for different configurations for wind power generation: for a single turbine and an average Belpex Day-Ahead Market price of 75.3 €/MWh, the fixed OTC-value for 2009 is determined at 66.3 €/MWh. The limited predictability of wind therefore leads to a revenue loss of 18% due to imbalance settlement.
It is found that this OTC-value can be increased with 16% when aggregating wind generation over larger areas and submitting this as one nomination (cfr. Germany).

Secondly, different nomination strategies are researched including the value of accuracy improvements concerning forecasting. For a wind farm of 8 MW, the OTC-value is determined at 68.6 €/MWh, including the imbalance loss of 14%, when using state-of-the-art prediction tools. The value increases with 5.5% when using intraday markets to adapt nominations to newer predictions.

As the tool was developed with data up to December 2008, resulting values and prices are rather high compared to the actual value in 2009-2011 (effect of the global economic crisis). The results below can therefore be best compared in a relative manner.

Phase 2: technical upper limit for wind power in Belgium

In the second phase of the project, constraints concerning the back-up of wind power in Belgium are studied. A simulation model, representing the short-term operation of the Belgian generation park, is developed and used to assess the limits of wind in the Elia control zone (Belgium and Luxemburg). All available power plants are assumed to be used in a cost-optimal way to cover demand in the control area. In first instance, network constraints and potential grid bottlenecks are not considered.

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Under these assumptions, technical barriers for wind are determined by the capacity of other available generation units to set off wind generation prediction errors. Overestimation of wind generation needs to be balanced by flexible capacity. These reserves can be activated to meet discrepancies between demand and supply. Underestimations result in identical requirements but can be resolved by wind generation curtailment when necessary. Results show curtailment of up to 7800 MWh for 24h for an installed wind power capacity of 3000 MW, depending on demand and wind power generation profile. Besides the technical barriers of integrating large shares of wind capacity in the system, the impact on operation costs and greenhouse gas emissions are determined.

Within Belgium, the potential of the generation system to balance variable generation by wind farms is limited. This barrier could be relieved by considering the whole of Europe, while making abstraction of potential grid bottlenecks. Combining power systems reduces the required reserves when separate system imbalances show limited or opposite correlations. Literature shows that wind power fluctuations and prediction errors can be smoothened when aggregating them over larger regions.

The assumption that no transmission bottlenecks are present in the Belgian and European grid is clearly an enormous simplification of reality. Therefore, one of the project deliverables focuses on methodologies for including detailed network simulations. Due to practical constraints, there has been opted to work with a DC load flow model serving as a simplification of AC load flow simulations.

Phase 3: balancing large wind power variations in Belgium

The final phase of the project focusses on the facilitation of massive wind power integration scenarios in the Belgian power system towards 2020. Focus is put on technologies and market mechanisms to cope with wind power variability.

Balancing technologies

Four main technologies with balancing potential are studied and assessed: first of all, large (pumped) hydro power plants are a very attractive option to overcome the variability of wind power as this technology is characterised with high flexibility and low operating costs. However, due to geographical constraints, their potential is limited in Belgium. Two pumped storage plants are currently present in Belgium with a capacity of 1164 MW (Coo) and 224 MW (Plate Taille). New innovative concepts are currently under research e.g. offshore ‘energy islands’ pumping water out of a reservoir resulting in electricity generation when allowing the water to flow back in trough generators.

However less flexible, combined-cycle power plants (CCGT) or peak power plants are generally assessed to have significant wind power balancing capabilities. CCGT plants can be started in 40-150’, achieve reasonable ramp rates and efficiencies. Peak power plants (turbojets, gas turbines and diesel motors) are characterised with higher flexibility (start-up, ramp rates) but lower efficiencies. The gas turbine starts generating power after 3’ and reaches full capacity in 6’.

Finally, two innovative concepts showing potential in balancing future wind variations are introduced: decentralised storage and demand response. Energy storage systems, characterised by prompt response and limited deployment time, can offer additional balancing capacity to the system. A large variety of storage technologies is currently available and under development showing a wide range of technical and economic characteristics. In contrast, demand-side response enables balancing capacity by means of shifting demand of consumers. In Belgium, first estimations veils a potential of 358 MW, only contracted from domestic appliances. This number is based on a minimum level of acceptance by consumers.
With the expected future integration of plug-in electric vehicles, the annual household consumption may double resulting in an important future potential, both for storage and demand response.

Market mechanisms for balancing wind

In most European power system, e.g. Belgium, wind power faces a market context implying balancing responsibility. Final responsible for balancing the overall system is the Transmission System Operator (TSO), (de)activating reserve capacity to restore the real-time balance between demand and supply. The costs of these balancing services are transferred to the responsible market players (BRPs) by means of imbalance tariffs. This implies additional costs for wind generators facing the limited predictability of output. This balancing responsibility for variable RES-E is an ongoing policy discussion.
In order to cope with uncertainty in their portfolio, BRPs in Belgium are able to apply different market mechanisms. As accuracy of predictions increases with closer prediction horizons, balancing costs can be reduced by enabling possibilities to adapt nominations intraday. Market mechanisms are designed enabling this with intraday trade and power exchanges. Intraday markets were introduced in Belgium as from 2008 and expanded with cross-border allocations. However, these markets remain characterised by low liquidity. This is expected to be improved with increasing market integration and competitive environments, and the physical availability of new flexible capacity.
Special attention is given to a particular Belgian regulation exempting offshore wind partially from the existing settlement mechanism. Generation deviations inside a margin of 30% of the nominated output benefit from capped imbalance tariffs.

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A preliminary study confirms a prediction error (RMSE) which is 2-6% higher for offshore locations. Although this regulation can be defended as it directly tackles the imbalance cost, this support mechanism is complex and not transparent. Capping the imbalance settlement tariffs weakens the link between the reserve market and the imbalance tariff, being a prerequisite for the well-functioning of balancing markets. Therefore, this support mechanism should rather be replaced by increasing the minimal price of the green certificates. This increase is estimated at 1.4-1.7 €/MWh.

Facilitating high wind development scenarios in Belgium

In view of meeting renewable energy targets towards 2020, the Belgian national renewable energy action plan targets an installed capacity of 4320 MW in 2020. The impact of this scenario is researched by means of the simulation model representing the short-term operation of the Belgian generation park. The model is therefore extended with network constrains through DC load flow. Wind is integrated in a model representing the Belgian power system including scheduled investments towards 2020. In addition, four cases are designed representing different combinations of balancing technologies.

First simulations reveal major integration problems as the generic model seems to be unable to facilitate the 4320 MW of wind distributed over the Belgian control zone. Firstly, certain network constraints occur in the coastal region, due to large offshore capacities, and in the South of Belgium, due to a less meshed grid. A series of additional grid reinforcements are proposed and included in the model. A second barrier for large wind power integration is the alleged inflexibility of the nuclear park as currently operated (in base load). Low demand combined with high wind generation may result in net demand lower than the base load nuclear park. Therefore, this study proposes to increase flexibility of the generation park by operating the nuclear power plants in modulating mode (cfr. France). A final barrier originates from the large imbalances which may occur due to wind-forecasting errors. Predefined capacity of 300 MW spinning reserves and 737 MW non-spinning reserves may not be adequate to balance wind power imbalances. Increasing the amount of reserves in order to be able to cover the largest possible forecast error may be unrealistic in the framework of generation adequacy. Therefore, in a final step, import and export are allowed in real-time at artificial high costs. This maintains the incentive to cover imbalances on a national level.

Results for the reference scenario reveal that nuclear regulation is needed mostly when a high wind power output is present during low demand. Furthermore, peak power plants are used regularly in all scenarios when only 300 MW of spinning reserve capacity is demanded from the system. Also import is required in order to balance the largest forecast errors. Export on the other hand is not used because nuclear power is assumed to be able to regulate its power output down to 60% of its nominal power. Increasing the amount of spinning reserves to 1055 MW reduces both the use of peak power and the import requirement, leading by consequence to a more secure Belgian power system.

In this study, the focus is put on the ability of the power system to balance wind power with national resources. The use of peak power plants and import is seen as a "problem" for security of supply and represent additional reserve capacity. Three technology cases, representing CCGT, decentralised storage and demand response, are therefore compared with the base case on this use of standing reserve capacity and import. Additionally, operational efficiency is investigated.

Due to fact that the model works on an hourly time-scale and spinning reserves are held constant to 300 MW, adding extra CCGT power plants will have no effect on the flexibility of the Belgian power system in balancing forecast errors. Adding in a third case decentralised storage units to the Belgian power system does not change the results to a significant extent. This is due to the small amount of decentralised storage added to the Belgian power system and the fact that a large amount of wind power integrated in the Belgian system (4320 MW) leads to some extent to large changes in power output. These large changes cannot be covered by such a small addition of decentralised storage. However, storage can still have an important economic impact on daily situations. Extending the amount of decentralised storage would probably yield more extended results, but is expected as difficult to obtain towards 2020. Last but not least, the base case is extended with 1000 MW of demand response: also in this case, the output of the model shows no significant difference in operational efficiency. The use of non-spinning reserve capacity and import decreases however in all scenarios considered, meaning that demand response is of good help in balancing wind forecast errors.

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CONTRIBUTION OF THE PROJECT TO A SUSTAINABLE DEVELOPMENT POLICY

The integration of a large share of wind energy is, because of variable production and limited predictability, a major challenge for the current electricity system. This integration is limited by technological, economic and regulatory realities based on a system of conventional and centrally located generation unit. The contribution of this project is to identify these barriers and to offer solutions. The results of this project can be used by the Belgian policy makers to increase the potential for wind energy.

One of the results represents a market simulator that allows to assessing the impact of competition on the profitability of wind energy. Furthermore, a simulation model is developed to evaluate the impact of wind on the entire system. Finally, technologies and market mechanisms are offered to help balancing generation and demand with the variable output of wind. These are integrated into the developed tools.

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