Using Ensembles for Large-scale Forecasting of Wind Power in a European SuperGrid context

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Abstract: This paper demonstrates the benefits and discusses the requirements of a European SuperGrid to be integrated into a common market structure in order to meet the targets set out by the European Commission for 2020 and 2030. A study has been carried out with a multi-scheme ensemble prediction system (MSEPS) to simulate a SuperGrid encompassing 8 countries around the North Sea with a total installed capacity of 44.6 GW. The results of the 2-year numerical simulation indicate that 30% or the forecast error can be avoided in this way. This result is brought into perspective and the implications, benefits and challenges of handling wind power in such SuperGrid scenario are discussed.

Key words: Ensemble forecasting, European SuperGrid, Wind Power Trading

1 Introduction

In order to fulfil Europe's targets of CO2 reduction on energy production in the next 2 decades, the deployment of wind power throughout Europe has to increase significantly from today's installations.

The targets set by most European countries can only be met with offshore wind power delivering the bulk of new production units. The coupling of electricity markets through-out Europe and the interconnection of offshore wind power in the North Sea, Baltic sea and parts of the Mediterranean sea will be a necessary step that eventually will lead to a centralized European SuperGrid connecting all European counties. This new grid structure will not only involve the enhancement of today's electricity network through more connection points, but will require focal points to collect, integrate and route the produced energy to the load centres and the markets with the highest demand. Such a European SuperGrid will also have to integrate all markets into one common market in order to enhance competition, the security of supply and reliability of the system for all countries in the EU.

An integrated European market also will require large-scale forecasting of wind power to ensure the efficient trading of electricity. By using ensemble forecasts of the large-scale wind power generation over entire Europe, the total reliability of the energy system can be maintained and further increased. The use of ensemble forecasts in this context in fact will reduce price volatility, as excess wind generation from one region can balance missing wind generation in other regions. Additionally, the total wind generation can be estimated more accurately with the use of large forecast ensembles.

1.1 Framework of the Simulation Study

The goal of the paper is to describe a framework in which the economic and technical feasibility of present and future renewable power generation can be compared with objective measures. The framework is build on WEPROG's MSEPS ensemble forecasting system, a system built upon the so-called multi-scheme ensemble approach. We have included most of the currently operational wind farms in 13 European countries (ca. 26260 wind farms/turbines) with a total installed capacity of 75GW. With the MSEPS system we are able to simulate forecast errors, locate extreme events and predict reserve requirements for all countries. Particularly, the benefit or need of new power lines and inter-connectors can be estimated for a given capacity distribution. The framework is therefore highly relevant for evaluating the impact of a SuperGrid for renewable energy.

2 Setup of the Experiment

The MSEPS system differs from other wind power prediction systems in many ways. First of all, the core of the MSEPS is a 75 member ensemble weather prediction system, which simulates the physical uncertainty of the weather forecasts well already after forecast hour six. The uncertainty predicted by the MSEPS is therefore equally relevant for intra-day forecasts than for multi-day forecasting.

The MSEPS system handles single wind farms with interpolation to the real location and dispersed wind power by integration into the NWP model's grid. What is most suitable depends on the distribution of wind farms. For the present study all wind power was considered as dispersed, because there is no specific interest in the output of the individual wind farms. Confidential measurements could also not be used for the validation. Instead ultra-short-term forecasts were used. This means that the wind power generation was approximated by essentially one wind farm per model grid point and centred in the middle of the grid point in a 0.45° grid all over Europe. The summation in grid point space preserves the border of the countries and electrical grid in order to separate the energy production by grid.

The distribution of wind farms in Europe has been calculated by special software developed to process publicly available data. Some countries have significantly more detailed data than other. The "WindPower.net"-database [1] has been used in a number of countries.

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However, a considerable amount of adjustments were required to adjust the capacity to a level, which is consistent with the publicly known capacity.

The power curves are generated from published aggregated data using a special technique to localise the generation to the *virtual* wind farms in each of the grid points. The localisation is iterative and distributes power generation onto the grid points according to the forecast. The process involves the following steps:

- Purely physical wind power prediction for 1220 grid points with all ensemble members
- Area integration of the power generation
- Computation of a time series of percentiles and ensemble average
- Computation of a bias correction as a function of predicted generation
- Adjustment of the percentiles and ensemble average with the bias correction
- Finding the so-called *true percentile value* corresponding to the actual generation to get the consistent local generation.

Finally it is assumed that the *true percentile* applies at any location and this assumption uniquely defines the *virtual* local wind farm generation. Thereafter follows a normal least square training. This training is done with the standard MSEPS approach, where direction dependent power curves are made for different stability classes. In this way, power curves for all regions were produced, where the aggregated wind power generation was published. In other regions the most relevant power curves are used. This is feasible, because Germany has for example wind turbines located in nearly all types of terrain, where the effective power curves are an average estimate of more than 25000 turbines. Reduced availability is therefore built into the power curves.

2.1 Forecasts and Observations

Wind power forecasts were produced for a period of 2 years from July 2008 to June 2010 for each of the 1220 *virtual* wind farms (grid points). Accumulation is then done for each ensemble member over each region/country of interest. To make the area integral of each ensemble member individually is fundamental, because the errors partially cancel each other out. This means that the larger the area, the lower the forecast error measured relatively to the total generation or installed capacity.

We then needed to define what should be considered the true generation, referred to later on as "estimated generation". This is done by using a weighted average of the ensemble members using a scheme, where the long-term verification scores are used to give weight to the individual ensemble members dependent on the weather situation. The most accurate prediction horizon from the NWP's perspective is the 6-11 hour horizon. This is after the noise caused by the new initial conditions in the weather forecast have levelled out. It allows us to define a complete time series, because new forecasts are generated every 6 hours. Although this time series is strictly speaking itself a forecast, it is possible to utilise the time series as independent measurements.

One could imagine that verification against the same weather forecast results in a lower error than against real measurements. This is not so, because wind power measurements are extremely sensitive to small changes in the weather forecast. A new wind field is therefore as independent as a new measurement. Although estimates do contain a perturbation of variable amplitude around the true measurement, long term average errors of day-ahead forecasts are of the correct magnitude. This is not so for shorter periods such as a month. A two year simulation is justifiable to be verified with such “fictive” measurements.

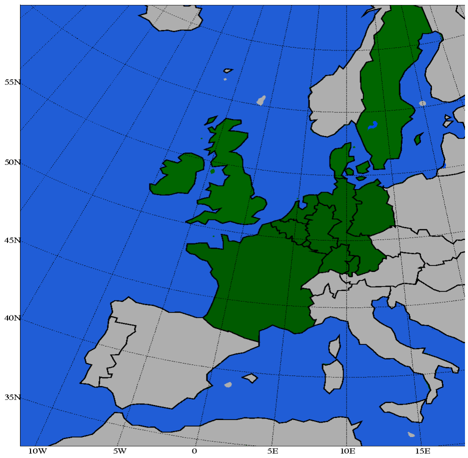

Figure 1: The selected 8 countries (green) for the SuperGrid

2.2 Test period and Area selection

The primary purpose of the SuperGrid is to establish a large market to facilitate sale of intermittent energy. In this SuperGrid study we focus on the various countries' energy generation pattern and on how the countries would interface with each other when connected in a SuperGrid.

The selection of countries was made on the basis of several factors such as weather pattern, wind power potential, geographical extent and inter-connector plans. The purpose of the selection is to create one coherent area, which often experience the same weather but slightly phase shifted. With this strategy, less fast acting and expensive capacity (fossil fuel) will be required and parts of wind power is balanced over inter-connectors. It is suggested that major parts of the wind generation peaks should always be exported as the peak moves from one area to the next. The export is maximised to the region, where the wind extreme is moving to next to take the peak and extend this more constant wind generation over time. The flow reverts as the extreme enters the new area. All regions will in this way experience smoother generation changes due to wind. The approach in fact cuts off the top of the generation peak in the small countries and increases the efficiency of he entire energy generation. One can imagine this process as a weather extreme moving through the British

Channel to the Netherlands. Instead of ramping fossil fuel down heavily within the Netherlands, part of the wind energy is first exported to Germany and as the extreme arrives in Germany, part of the energy is send back. The result is a softer generation profile and less disturbance from wind in both countries.

An objective measure for how well areas fit to each other can mathematically be expressed in terms of correlation between the individual generations. We selected only countries with a correlation above 0.4 to at least one neighbour country for our study (see Table 1). A lower correlation effectively means that the countries can exchange positive and negative imbalances in wind power too seldom.

country	ec	eu	ie	de	dk	at	be	es	fi	fr	it	nl	no	se	uk
ec	1	0.94	0.29	0.88	0.67	0.23	0.72	0.45	0.21	0.61	0.24	0.79	0.22	0.51	0.66
eu	0.94	1	0.32	0.95	0.74	0.14	0.77	0.13	0.19	0.58	0.02	0.86	0.17	0.52	0.72
ie	0.29	0.32	1	0.17	0.21	0	0.28	0.04	0.09	0.2	-0.06	0.29	0.15	0.17	0.42
de	0.88	0.95	0.17	1	0.68	0.2	0.63	0.1	0.14	0.45	0.01	0.74	0.09	0.45	0.49
dk	0.67	0.74	0.21	0.68	1	0.03	0.34	0.06	0.21	0.16	-0.07	0.51	0.2	0.68	0.53
at	0.23	0.14	0.00	0.2	0.03	1	0.04	0.19	0.02	0.1	0.39	0.03	0.04	0.06	-0.04
be	0.72	0.77	0.28	0.63	0.34	0.04	1	0.09	0.1	0.82	0.05	0.86	0.08	0.25	0.59
es	0.45	0.13	0.04	0.1	0.06	0.19	0.09	1	0.09	0.24	0.39	0.06	0.13	0.12	0.08
fi	0.21	0.19	0.09	0.14	0.21	0.02	0.1	0.09	1	0.12	0.04	0.13	0.46	0.56	0.14
fr	0.61	0.58	0.2	0.45	0.16	0.1	0.82	0.24	0.12	1	0.21	0.6	0.14	0.17	0.4
it	0.24	0.02	-0.06	0.01	-0.07	0.39	0.05	0.39	0.04	0.21	1	0.01	0.12	0.02	-0.03
nl	0.79	0.86	0.29	0.74	0.51	0.03	0.86	0.06	0.13	0.6	0.01	1	0.11	0.34	0.74
no	0.22	0.17	0.15	0.09	0.20	0.04	0.08	0.13	0.46	0.14	0.12	0.11	1	0.47	0.17
se	0.51	0.52	0.17	0.45	0.68	0.06	0.25	0.12	0.56	0.17	0.02	0.34	0.47	1	0.34

Table 1: Results of the weather correlations of the original 13 countries. 8 countries with a correlation >0.4 were selected for the study. Here, "eu" is the average of the 8 countries and "ec" of all countries.

For the sales process a lower correlation is clearly a benefit in order to avoid simultaneous generation, but the balancing and fit to the demand are also key objectives for integration of wind.

The correlations were computed on the basis of a 2 year time series of generation for each country. This was sufficient to find 8 correlated countries: Ireland, United Kingdom, The Netherlands, Belgium, France, Germany, Denmark and Sweden with a combined installed capacity in July 2010 of 44GW.

Strictly speaking, the northern part of Sweden and the southern part of France rather fit to separate areas and should count there, in an extended study of all European regions .

3 Results of the SuperGrid Study

Figure 2 shows the frequency distribution if the 8 countries and the SuperGrid. It is worthwhile noting that there will not be a likelihood for concurrent generation of more than 50% of installed capacity and practically no risk for no generation.

The statistical results for the day-ahead horizon is presented in Table 2 by country and for the entire SuperGrid. The most interesting result is the relative difference between AVR and SuperGrid. It can be seen that the SuperGrid is nearly 30% less than AVR. Here, AVR is the capacity weighted error for the 8 countries assuming that no forecast errors are exchanged across interconnectors between countries whereas SuperGrid is the result of exchanging errors over the interconnectors whenever possible.

Another interesting result is that the error in the Netherlands is reduced by more than 50%, if errors were exchanged. This is so, because the Netherlands is lying in the middle of the area and can easily exchange errors in all directions. This possibility will be expanded as the North Sea offshore capacity grows. In fact, the result for the Netherlands shows the core of the approach and why high correlations between the countries are required to make the balancing feasible.

The gain from the SuperGrid in percent is in general highest, where there is wind power on both sides of a common border. The results indicate that a consistent and intelligent handling of the generation near borders will reduce the effective error. Increased offshore wind power will over time also provide a similar smoothing on the coast line side.

France has several high wind power concentration areas along borders, which is very suitable for balancing, which will be required in the future, because the nuclear generation is not flexible to be used for this purpose. Therefore, France is a country, which may benefit significantly from a SuperGrid.

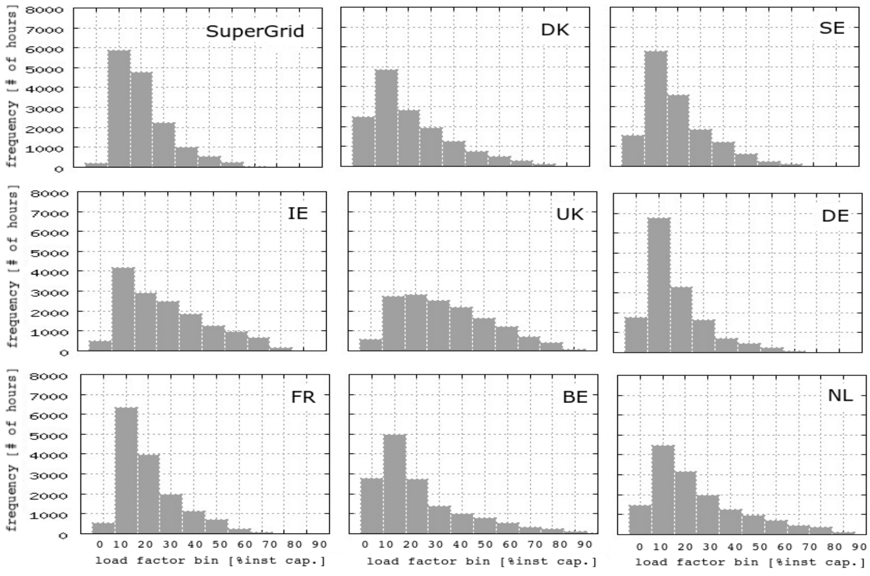

Figure 2: Frequency distribution of the 8 countries and for the SuperGrid.

The underlying data material has shown that Germany gains internally approximately 30% by using the load balancing SuperGrid-principle (in German context called “HOBA”) across the four TSO zones and it is therefore interesting to note that another 20% of the error could be exchanged with other countries.

So, even though Germany is very dominant with 56% of the total capacity, it is still possible to reduce the forecast error considerably by using interconnections with much smaller countries with less capacity. This is so, even though Poland is not among the 8 selected countries. A closer study on Germany has indicated high uncertainty on Germany's east border. Thus, the 20% gain for Germany is a conservative estimate of what Germany could gain from the SuperGrid.

The overall result is that 600-700MW of balancing power can be saved by enlarging the grid, where Germany alone saves 180MW. Today, there is most likely no attempt to exchange any of these errors. Instead, reserve capacity is bought on the market. There is no central management system telling that wind is out of balance in one control area nor are there parties seeking partners for such imbalances.

Country	BIAS [% inst. cap]	MAE [% inst. cap]	RMSE [% inst. cap]	STDV [% inst. cap]	CAP [MW]	RMSE [MW]	Gain [MW]
BE	-0.09	4.28	6.8	6.8	642	44	22
DE	0.37	2.54	4.08	4.06	25500	1040	189
DK	-0.21	3.79	5.74	5.74	3200	184	77
FR	-0.06	2.65	4.02	4.02	4709	189	32
IE	-0.36	4.06	5.83	5.82	1412	82	35
NL	-0.09	4.48	6.86	6.86	2775	190	98
SE	0.61	2.76	4.12	4.07	1537	63	12
UK	-0.49	4.25	5.97	5.95	5089	304	134
AVR	0.14	3.03	4.67	4.66	44864	2097	598
SuperGrid	0.14	2.16	3.34	3.34	44864	1498	-
ratio	1.0	0.7	0.7	0.7	-	-	-
saving	-2.8	28.8	28.5	28.3	-	-	-

Table 2: Statistical Results of the 2-year SuperGrid simulation for 8 European countries, their average (AVR) and the SuperGrid.

4 Conclusions and future Outlook

The presented statistical results show that enlarging the grid intelligently, opens the possibility to save nearly 30% in balancing capacity, equivalent to 600-700MW for a combined capacity of 44GW of wind power. The results indicate that further improvements could be achieved from offshore wind power in the North Sea, Baltic Sea and inclusion of Poland. All countries have a gain and all power plant will operate more efficient than present.

Although a market coupling has a built-in capability to adjust the export/ import of primary power, it is expected that the above mentioned 600MW saving goes on top of the benefits of the market coupling.

The results are extremely promising for the existing and planned offshore wind power, where more connections across the North Sea will open the possibility to get a much higher utilization of the North Sea wind power. This will be the next step in this study to be included.

From these encouraging results, it is nevertheless tempting to think ahead and consider how such a SuperGrid can be brought into operation. Can the system work with the current market coupling, national TSO's, different national incentive schemes and different ways of recovering balance costs ?

The way forward is to expand the German load balancing principle (HOBA) to the SuperGrid, but with centralized forecasting managed by a Market Operator (MO). The MO's obligation would then be to sell all non-scheduled wind power on the basis of conditional meta-forecasts. The conditional meta-forecasts would cover three scenarios:

- Full import => Lower uncertainty band active
- Not congested => Use standard forecast
- Full export => Upper uncertainty band active

This scheme would be grid secure with a N-1 control check on the interconnectors to ensure that wind power will be distributed by the market system. The scheme would also ensure maximum competition on reserve internally, as well externally in each control area.

The modification of the forecasts cannot change the flow direction, but the prices are likely to change. The import case is likely to increase the price and the export case will lower the local price, dependent on the prices in other price zones.

The MO would also have to run short-term forecasts to balance wind on the entire grid and deduct the cost of that from what is recovered from the sales on the day-ahead market. The MO would pay each TSO that eventually pays the wind farm owners according to the national incentive schemes.

The system would not be able to develop without a central regulation though, because the conditional forecasts would have to be implemented via a EU-regulation, as well as shared balancing across control areas would have to be implemented in the regulation. There will most likely also be confidentiality obstacles on the generation data required for efficient forecasting. Thus, this is so far mostly a possible way forward from a theoretical study. However, the ideas could be used for extreme cases on TSO level already and in this way increase grid security.

The presented results encourage to carry out a more in depth study to quantify how much of the error can be exchanged in practise with the current transmission capacity and the planned (offshore) future capacity. In that way, it could also be found out, where the bottlenecks are in wind power context and, where on the grid additional interconnectors should be added.

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