# Aggregate Forecasting of Wind Generation on the Irish Grid Using a Multi-Scheme Ensemble Prediction System

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## Abstract:

Accurate wind generation forecasting is an important requirement to enable higher levels of wind generation on the weakly-interconnected Irish power system. Higher wind penetration is necessary for security of energy supply reasons, as well as to contribute towards Kyoto targets.

A Multi-Scheme Ensemble Prediction System (MS-EPS), the first short-range ensemble prediction system that has been employed for wind power forecasting, has been applied to total wind power production data for the aggregated wind capacity on the Irish grid for the first three quarters of 2005.

Preliminary results indicate a mean forecast error of ~ 6%. This is very favourable when compared to typical single site forecasting errors, which can be up to twice this value. However, the real benefit of the ensemble technique is its ability to provide a physically meaningful uncertainty of each forecast.

Aggregate ensemble forecasting of wind generation therefore offers a TSO the ability to handle higher wind penetrations (particular on weak grids) more securely, through more accurate forecasting, as well as the possibility of forecasting reserve demand in real-time basis, due to the quantitative uncertainty information provided by the ensemble.

**Keywords:** wind generation forecasting, ensemble prediction, forecast uncertainty, reserve demand

## 1. Introduction

The ability to increase the penetration of wind energy generation onto the Irish grid is limited because of the size of the grid and the weak interconnection to other synchronous power systems [1].

Higher wind penetration is necessary for both economic and environmental reasons, namely security of supply and to assist in meeting Ireland's commitments under the Kyoto Protocol.

In the past, the relatively low level of predictability of wind power has been one of the main barriers to increasing wind energy penetration, as it increases the costs associated with operating reserves and balancing intermittent wind generation [2]. However, with the advent of ensemble prediction systems for weather forecasting, it is now possible to have reliable wind power forecasting as well as a quantifiable estimate of the forecasting uncertainty. Both of these features are urgently required by grid operators with large wind penetrations, in particular those operating island or weakly-interconnected systems. They will enable high wind energy penetration while at the same time ensuring power system security and stability.

The power system in the Republic of Ireland is a case in point. By December 2005, a total of 498MW of wind power had been installed and a further 760MW had connection agreements [3]. The total installed generation capacity is over 6,400MW, with a maximum demand peak of >4,800MW and a minimum summer load of >2,000MW, i.e. within a few years it is possible that wind could contribute up to 65% of the summer valley. Weak interconnection with the Northern Irish grid, which itself is only weakly connected to Scotland, exacerbates this problem.

Few other options are available to maintain a secure grid and balance power effectively. Storage opportunities and stronger interconnection (N-S and E-W) will possibly only contribute in the longer term [4,5]. It is therefore imperative that forecasting wind generation on the Irish grid is both accurate and has the ability to provide quantitative information on the uncertainty of the forecasts [6,7].

## 2. Wind Power Forecasting

### 2.1 Traditional Prediction Methods

There are a number of different types of wind power forecasting methods and systems currently in use [8]. Most of these systems are based on different combinations of persistence, physical or statistical models. However, they mostly rely on deterministic weather forecasts, usually provided by national meteorological services, which can cause occasional high errors in atypical weather situations, as there is usually no indication available of uncertainty attached to each forecast.

### 2.2 Ensemble Prediction Methods

Ensemble forecasting, i.e. using a collection of forecasts instead of only one deterministic forecast, has been developed in order to quantify forecast uncertainty and to improve the accuracy of deterministic forecasts. Until now, ensemble prediction systems have been developed by national met services for medium-range weather forecasting purposes only, e.g. [9]. Some have been applied in short-term wind power forecasting, e.g. [10,11].

Multi-model and multi-scheme methods have also been developed, both for weather forecasting and short-range wind power prediction, e.g. [12,13,14,15].

### 2.3 Multi-Scheme Ensemble Prediction

Multi-scheme ensemble prediction is a technique where different parameterizations, or 'schemes', are used to vary the formulation of the fast meteorological processes (e.g. vertical diffusion, condensation), giving the potential to provide a more realistic representation of the state of the atmosphere and a smaller ensemble bias [16].

One such system is the 75 member, limited-area Multi-Scheme Ensemble Prediction System (MS-EPS), initially proposed by Möhrlen [14] under the wind power forecasting research program at University College Cork, and further developed to a 75 member ensemble by WEPROG, who operate the system as a full commercial service. It is, to the authors' knowledge, the only short-range ensemble prediction system operational world-wide at present.

Model resolution employed for this study was 45km, although it can be run at higher resolutions. The system was described in detail by Lang et al [17].

## 3. Irish Results

### 3.1 Method

The MS-EPS has been extensively validated in Denmark and Germany [17] and now its suitability for Irish conditions has been the subject of a preliminary validation study. The study involved the comparison of a range of forecasts for total Irish wind farm power production, over a nine month period in 2005.

Power production data for the period were obtained from the Transmission System Operator (TSO) in Ireland, ESB National Grid, for total wind generation. This was provided as total MW data in 15 minute time-steps, for the period 1/1/05 – 30/9/05.

The ever-increasing Irish installed wind capacity amounted to 498MW by end of 2005 (51 wind farms, counting extensions to existing wind farms as new wind farms). A number of wind farms were progressively added to the forecasting system, based on their commissioning and export start dates during 2005. Locational data was provided by ESBNG and in some cases supplemented by more detailed data from wind farm operators.

Observational data were only available as aggregated total power for all farms that were connected to the grid. Therefore, training of the forecasts to the observations was limited to an adjustment of the total production from the sum of the power predicted at those wind farms that were grid connected.

The following procedure was then used to compare forecast power with observed power:

1. The observed power data were averaged to hourly values in order to compare with the MS-EPS output.
2. Data output from the MS-EPS for the period 1/1/05 – 30/9/05 were collated. These were the hourly forecasts produced at 00 UTC each day, for each of the 75 ensemble members, out to a horizon of 48 hours.
3. Each ensemble member's forecast at 30m agl (u, v components for each hour) was interpolated to each wind farm site from its location relative to the four closest grid points.
4. Forecasted wind power outputs at one hour intervals, for each ensemble member, were produced for the aggregate wind generation on the Irish grid.
5. The statistical 'best guess' of the forecast power was calculated using the probabilistic method described by Möhrlen [14].

An example of the forecast system output of observed power, EPS mean, maximum, minimum, and the best guess is shown in Figure 1. This shows the 00 UTC model run for 7/1/05, with forecasted wind power out to 48 hours ahead. Vertical axis is the load factor (0-100% of total installed wind generation capacity) and the horizontal axis is the time of day.

The ensemble members' probabilistic distribution is shown by the grey and black contours, or envelope. The darker areas of the envelope represent the highest values of the probability density function (grouping of most ensemble members).

Note, the ensemble spread in this example is highest in the middle of the forecast, rather than at the end, as is often assumed. This example illustrates that the MS-EPS generates uncertainty with a physical meaning, as the spread is (mostly) independent of the forecast length over a 48 hour forecast horizon.

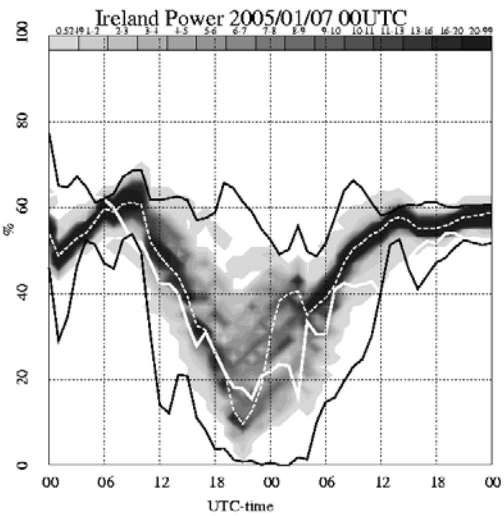


**Figure 1**: Example of a 0-48 hour forecast shown in a probability plot generated by the MS-EPS for the 7th January 2005. The upper and lower black lines denote the EPS minimum and EPS maximum, the white dashed line denotes the statistical best guess or "optimal" forecast and the white solid line denotes the actual total power observations.

### 3.2 Error Assessment

Error descriptors that are commonly used in the evaluation of prediction systems have been calculated here, in order to assess forecast quality: Mean Absolute Error (MAE), bias, standard deviation (SD) and the Root Mean Square Error (RMSE) [8].

These standard error descriptors are given as a percentage of the installed capacity of the wind farms in the aggregate area. This is more sensible than quoting an error as a percentage of actual total generation, which misrepresents the forecast error by suggesting very large errors for low wind generation. Similarly, quoting errors in absolute power units does not allow comparison between different forecasting systems.

The mean absolute forecast error is calculated from:

$$\text{nMAE} = \frac{\sum |P_f - P_o|}{c \cdot P_{inst}}$$

where $P_f$ and $P_o$ are the forecast and observed power, $P_{inst}$ is the installed wind power capacity, and the summation is over the number of time steps ($c$) for which both forecasts and observations exist.

Definitions used in the validation and error analysis of the MS-EPS as applied to Ireland are described in detail in [18].

### 3.3 Forecast Errors

The forecast errors for the aggregated Irish wind capacity are presented below in Table 1. All statistics of wind power forecasts have been computed with model wind speeds at 30m agl, using 24-48 hour forecasts for each day's 00 UTC model run.

| | |
|---|---|
| Aggregate Capacity (at end-2005) | 498MW |
| Average Load Factor | 30.1% |
| nMAE | 6.2% |
| Standard deviation | 8.3% |
| RMSE | 8.6% |
| Bias | 1.9% |
| $R^2$ (Correlation) | 0.90 |

**Table 1.** Forecast errors for aggregate Irish wind farm capacity. Verification results for 1/1/05 – 30/4/05, with training for 1/5/05 – 30/9/05. The total installed capacity varied within the training/adjustment and verification period. Therefore the number in the table is an approximate value at the end of 2005.

The frequency distribution of the errors is provided below in Figure 2.

## 4. Discussion

The results show that the average forecast error, when forecasting the aggregate wind capacity on the Irish grid using the MS-EPS, is 6.2%, with a standard deviation of 8% (normalised to the total wind capacity).

These are very encouraging results, considering the forecast error was 11.4% (with a standard

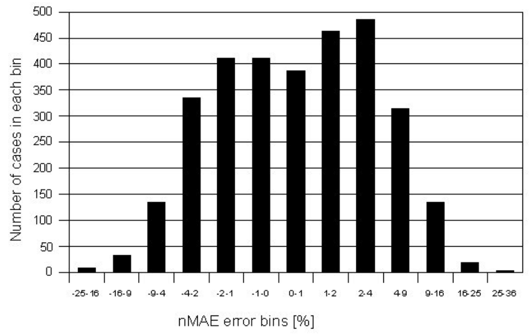


**Figure 2.** Frequency distribution of nMAE forecast error for aggregate Irish wind capacity, 1/1/05 – 1/4/05.

deviation of 16%) when forecasting for a single site wind farm in Co. Donegal in the northwest [17]. It appears that an analysis of a widely dispersed number of wind farms has led to a dramatic reduction in forecasting error, and suggests that aggregated power prediction is superior to single site prediction.

More importantly, it has provided a more realistic picture of the forecasting quality the Irish TSO should expect. However, the result is preliminary, as there is potential for further improvements once a more thorough training of individual wind farms can be conducted and the forecasting of the prediction error from the ensemble spread is taken into account.

These results agree with those of the International Energy Agency [2], who suggested that aggregation of wind power over many sites would reduce the error contribution from weather forecast phase errors, and similar studies in Denmark and Germany [17]. The smoothing effect filters wind farm fluctuations and allows the possibility of installing more wind power onto a power system. These individual wind farm output fluctuations can be substantial, particularly for very large wind farms, e.g. [19].

The importance of aggregation of wind farms, for the forecasting of wind generation, therefore becomes increasingly important with the increasing installation of larger capacity wind farms in Ireland, and this will have significant impacts on scheduling spinning reserve.

The new Transmission Grid Code stipulates that all wind farms of capacity over 30MW must provide MW output forecasts 48 hours ahead on a half hourly basis [20]. Balancing costs will be much higher if treating these large wind farms in isolation. However, linking the results of this study to recent work carried out on reserve requirement [21] shows that with a large wind capacity geographically dispersed, the aggregate forecast error using the MS-EPS is sufficiently low to require only minimal reserve demand. In addition, the MS-EPS will allow calculation of these system balancing requirements on a real-time forecast basis, due to the quantitative uncertainty information provided by the ensemble.

## 5. Conclusions

The ability to forecast wind power accurately and provide a quantification of the forecast uncertainty is imperative in order to enable higher wind penetration on the Irish grid, as it will reduce balancing costs and aid in maintaining power system security and stability. This is particularly important on island systems or those grid systems with only weak interconnection to large neighbouring grids, such as in Ireland.

A multi-scheme ensemble prediction system (MS-EPS) has been applied to total wind power production data for the aggregated wind capacity on the Irish grid for the first three quarters of 2005.

These results indicate a mean forecast error (calculated as a normalised mean absolute error, nMAE) of ~ 6%, with a standard deviation of ~ 8%.

This is a very promising result, particularly with regards to the improvement compared to forecasting power output for a single wind farm in complex terrain in the northwest (nMAE ~ 11%).

The improvement over single wind farm validation is in line with studies on the German and western Danish grids and findings by the International Energy Agency.

Aggregate forecasting on the Irish grid offers the TSO the ability to minimise balancing costs, thereby maximizing the economic value of wind, minimizing its environmental cost (by minimizing spinning reserve) and to ultimately enable higher wind penetration on the grid. However, the real benefit of the ensemble technique is in its ability to provide a physically meaningful uncertainty for each forecast, and this quantity may be usefully applied to the problem of forecasting the reserve demand on power systems with significant installed wind capacity.

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