NEXT GENERATION SHORT-TERM FORECASTING OF WIND POWER RESULTS OF THE ANEMOS PROJECT

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Summary

Wind power prediction is an essential tools for energy markets with high wind energy penetration. In the framework of the ANEMOS R&D project, advanced wind power forecasting technologies were developed, improved, and benchmarked. Promising physical and statistical approaches were implemented on a generalised ICT platform as an advanced wind power prediction system. The operational prediction system including a big variety of specialised models was tested at eight end-users including utilities and TSOs and is already under commercial exploitation.

1 Introduction

Accurate forecasting of wind farm production up to two days ahead is recognized as a major contribution for reliable large-scale wind power integration. Especially in a liberalized electricity market, prediction tools enhance the position of wind energy compared to other forms of dispatchable generation. ANEMOS was a four years R&D project supported by the European Commission with a strong focus on application which was successfully finished in September 2006. It brought together research organizations, developers and end-users with an important experience in the respective areas wind power prediction, wind energy meteorology, numerical weather prediction, economics, electricity generation, transport and distribution, and ICT system developments.
This paper presents an overview of the methodology and the achievements of the project.

2 The Project

The project aims to develop advanced forecasting models that substantially outperform current methods. Initially, the prediction requirements were defined in collaboration with a group of end-users. Then advanced physical and statistical prediction models based on existing operational models were developed.
Research on physical models emphasised on the application of techniques for use in complex terrain like CFD approaches, advanced model output statistics and high-resolution meteorological information. Statistical models were developed for downscaling, power curve representation and upscaling for predictions at regional and national level.
Appropriate physical and statistical prediction models were also developed for offshore wind farms taking into account advances in marine meteorology (interaction between wind and waves, coastal effects). Emphasis was put on modelling wake effects and spatio-temporal correlations of large offshore farms.
The benefits from the use of satellite radar images for modelling local weather patterns was investigated.
Advanced operational methods appropriate for the case of wind power were proposed for uncertainty and prediction risk estimation.
The project was structured into nine work packages which addressed the following technical objectives:

- Data collection & evaluation of needs
- Off-line evaluation of prediction techniques
- Development of statistical models
- Development of physical models
- Offshore prediction
- ANEMOS prediction platform development
- Installation of the platform for on-line operation
- Evaluation of on-line operation
- Overall assessment and dissemination

The following paragraphs present an overview of the various developments.

3 End-user Needs

As wind penetration increases, end-user requirements diversify and become more and more complex. Even throughout the current project new priorities emerged (i.e. uncertainty estimation, upscaling) revealing the necessity of research to meet requirements. In the future it will be necessary to continue research in the field: go back to the basics, develop further synergy with meteorology, work on the "value" of wind forecasting. The "value" relates to the integration of predictions and their uncertainty in management functions and decision making processes related to wind power.
The output of this research is expected to facilitate wind power integration at two levels. First, at an operational level, since it will allow better management of wind farms and more efficient participation of wind production in the electricity markets. Second, it is expected to contribute in promoting an increase in the installed capacity of wind farms: an accurate power prediction capability reduces the risk to wind farm developers, who are then more willing to undertake new wind farm installations, especially in a liberalized electricity market environment.

At a first stage of the project several audits with various actors like utilities, transmission or distribution system operators, independent power producers, regulatory authorities, etc. took place. With the aid of appropriate questionnaires, the requirements related to wind power prediction were evaluated. Emphasis was placed on the experience which end-users have with existing forecasting tools (confidence, level of use, etc). The results were synthesized to an "end-users requirements" report that gives a basic guideline for the developments in the project.
Moreover a detailed mapping of the literature on wind power forecasting was performed with the review of more than 120 references. A detailed report is available online at [2], for a summary see [1].

4 Model Benchmarking

A benchmarking process was set up to evaluate the performance of the developed models and to compare them with ten existing prediction systems. A number of six representative test cases characterised by different climatic conditions and terrain complexity (flat terrain, slight complex terrain, complex terrain, offshore wind farms) was used.

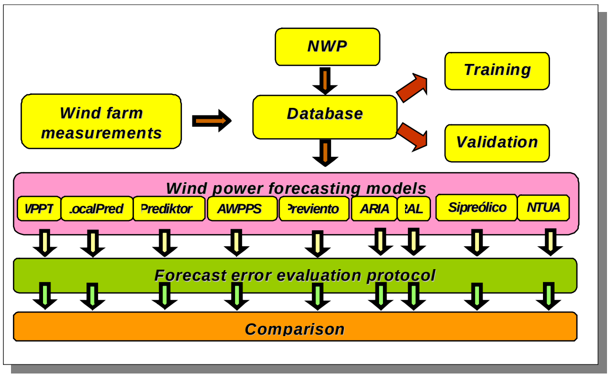

Fig. 1: Design of the virtual laboratory set-up for the models benchmarking.

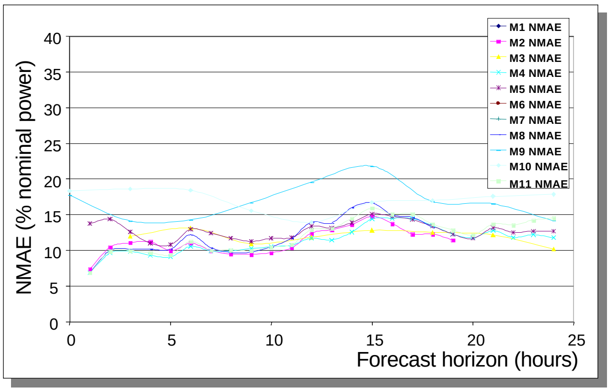

Fig. 2: Comparison of the performance of 11 prediction models on the Alaiz wind farm in Spain (very complex terrain). The NMAE is given as a function of the prediction horizon, which here is 24 hours ahead.

The ANEMOS project provides an advanced technology for wind power forecasting applicable for a single wind farm, at regional or national level and in both interconnected and island systems. The outcome of the ANEMOS project is expected to consistently help the increase of wind integration at an operational level through an optimised management of the risks related to the intermittent nature of wind generation.
One main result of all benchmarking processes was the fact that in general there is no "killer model" which outperforms the other models for all applications. The selection of an appropriate model strongly depends of the type of terrain **and** on the prediction time horizon.
This led to two main consequences: first, to improve wind power prediction, it is crucial to use multi model approaches applying models based on different mechanisms. Second: to handle this multi-model approach practically, a new so called *combination model* was developed. This is a statistical model which combines the output of different models according to their historical performance taking into account the time horizon and the overall weather situation.

5 Advanced Statistical Modelling

A large number of methods have been investigated for the prediction of power production or local meteorological variables including neural networks, fuzzy logic, Kalman filtering, support vector machines, radial basis functions, combined forecasting, and others. These techniques permit to combine various types of input like wind direction, wind speed from neighbour sites, numerical weather predictions etc.

6 Advanced Physical Modelling

In this project focus was given to challenging situations like prediction of wind farm output at complex terrain sites. A possible solution to that challenge comes in the form of high-resolution, advanced numerical flow models compensating NWP model shortcomings.

7 Uncertainty and risk

One main priority of the project concerned uncertainty of wind power prediction. Methods for assessing the situation-specific uncertainty in the power predictions have been developed being able to provide prediction intervals for pre-selected confidence levels – see Fig. 3.
Furthermore, prediction risk methods were developed to exploit information in ensemble meteorological forecasts for assessing the expected level of uncertainty in wind power predictions. This information can be particularly useful for the decision making processes related to wind power management or trading. The risk indices provide a complementary tool to prediction intervals. So a level of uncertainty may be forecasted – see Fig. 4. I.e. when a high value of the risk index is expected for the next day, the operators may adapt their strategies by taking preventive actions (e.g. ordering more balancing power).

The various statistical methods have been implemented in modules and integrated within the ANEMOS prediction platform and are operational in the various installations of the project.

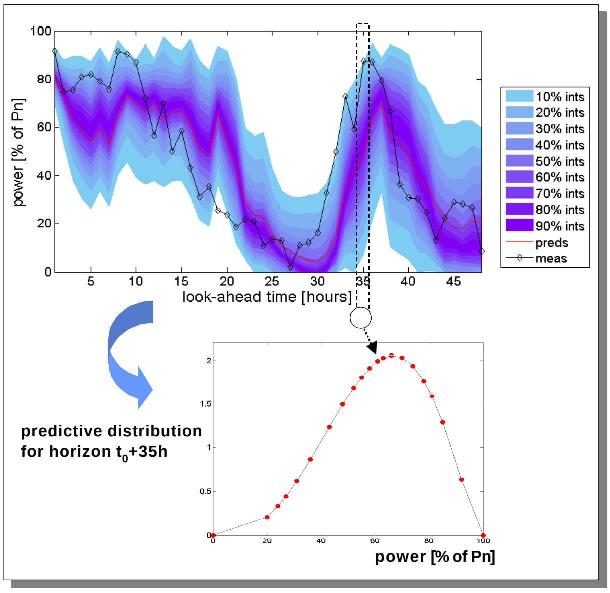

Fig. 3: Example of forecasts for the next 48 hours compared to measured values. Prediction intervals for various levels of confidence are displayed. Intervals are estimated with an adapted resampling approach.

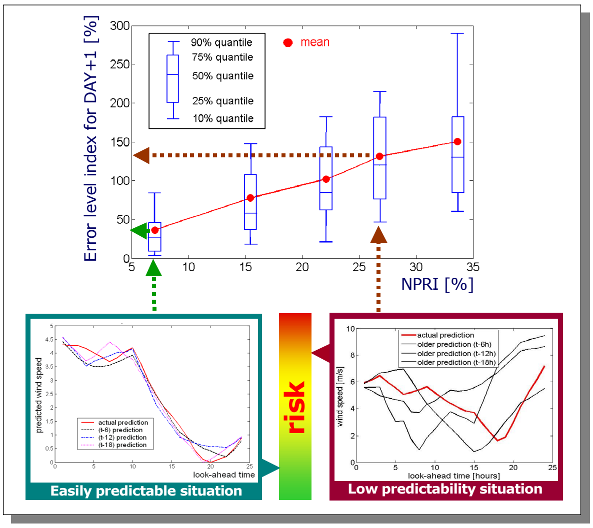

Fig. 4: Translation of weather predictability to power predictability for next day using the Normalised Prediction Risk index (NPRI). Bottom-left: the alternative predictions for the next day are very similar giving high confidence in the prediction. Bottom-right: the alternative predictions significantly differ – this lowers the confidence on the predictability of the weather situation. Each situation is represented by a value of the risk index. Using the upper diagram this can be translated to an error level of the power predictions (100% corresponds to the average error level of the model).

8 Benefit evaluation

For different market situations, the economic benefit of increased reliability of predictions was assessed in detail (Fig. 5). Combining different approaches lead to a significant improvement of the value of the wind power predictions. Although the improvement which can be gained by future work seems to be small, it should be kept in mind that target applications include markets like national balancing power market with turnovers of billions of Euros.

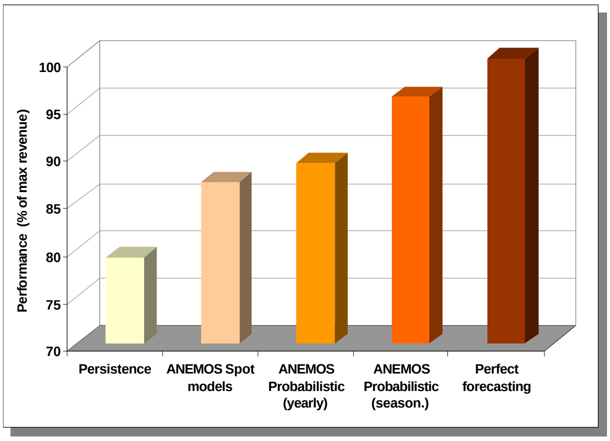

Fig. 5: Evaluation of the revenues obtained by participation of a wind farm in an electricity market with advanced wind power prediction support.

9 Software Platform

A next generation forecasting software system, the ANEMOS system, was developed in the framework of this project. It is fully operational and applied for commercial wind power prediction services. The system consists of a generalised platform with advanced Information & Communication Technology functionality. On this bases, the prediction models and tools developed (like probabilistic forecasting) are working on respective standardised interfaces. General purposes like processing and storing of time series and standing data in data bases, GUIs, scheduling etc. are handled centrally and are accessed via standardised and well-defined interfaces. This decreases the expenses for implementing new prediction models significantly.

The software system can operate both in stand alone, remote or in distributed mode combining different servers at distinct places. Interfacing with standard Energy or Distribution Management Systems is also implemented. The prediction system ANEMOS is now installed in seven countries for online operation by eight end-users including Transmission System Operators, utilities and others and is running currently for two fully commercial applications.

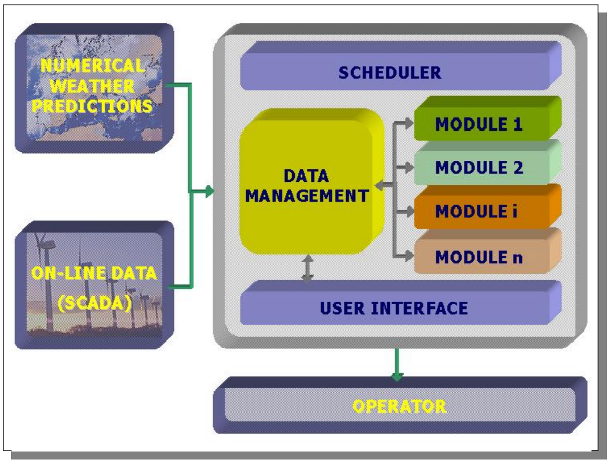

Fig. 6: General architecture of the Anemos prediction system.

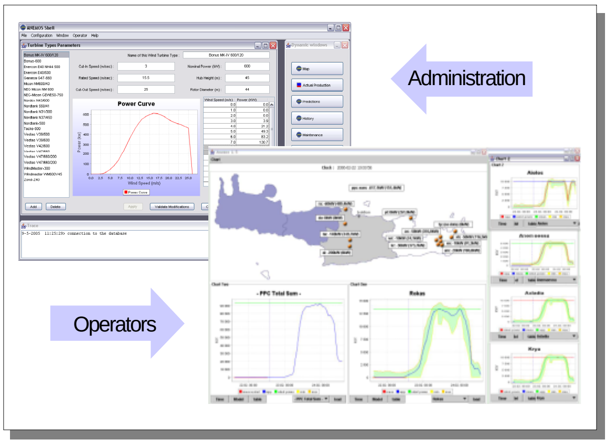

Fig. 7: Ergonomic graphical users interfaces were developed to visualise predictions and administrate the system.

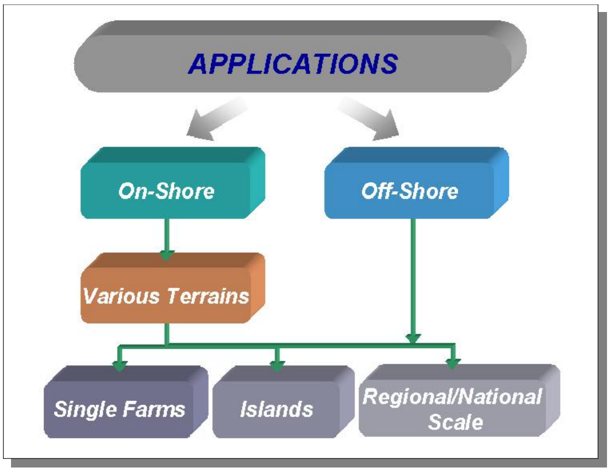

Fig. 8: A wide range of on-line applications were investigated for detailed evaluation and optimal exploitation of the results.

10 Conclusions

The ANEMOS project provides an advanced technology for wind power forecasting applicable on a large variant of applications: for a single wind farm, at a regional or national level and for both interconnected and island systems. For detailed information on the results of the project, a list of references is given on our web site.

A next generation forecasting software product, the ANEMOS system, has been developed integrating a variety of modules and covering a wide range of requirements for wind prediction and uncertainty estimation. The system now also has been tested and under fully commercial operation for more than a year.

The benefits of advanced forecasting are under evaluation during on-line operation, while guidelines will be produced for the optimal use of wind prediction systems.

After four years of the project, it is worth mentioning that the large size of the consortium in this case has been extremely beneficial. It permitted to establish a high level of synergy between experts from various fields. It led to achievements that would have been very difficult for single partners or smaller groups to realise. It permitted an accurate 'mapping' of the wind forecasting technology useful for developing grid and market regulations. Moreover, having end-users with different perspectives regarding wind prediction permitted to have a clear view regarding requirements and priorities. Last but not least, it permitted to create a data base of valuable information (like production and NWP data) for extensive validations of the modelling work. The project has globally contributed to extend the wind power forecasting technology as shown below:

- ❖Deterministic forecasting ➔ towards probabilistic
- ❖Classic model chain ➔ new solutions (combined models, multiple NWPs, ensemble predictions)
- ❖Accuracy oriented ➔ Accuracy + value
- ❖Research tools ➔ standardized pre-industrial tools commercial installations

Acknowledgements

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[2] Giebel, G., Kariniotakis, G., Brownsword R., *“The State-of-the-Art in Short-Term Prediction of Wind Power – A literature Review”,* available on line at http://anemos.cma.fr

[3] http://anemos.cma.fr

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