ANEMOS: Development of a Next Generation Wind Power Forecasting System for the Large-Scale Integration of Onshore & Offshore Wind Farms.

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Abstract - **This paper presents the objectives and the research work carried out in the frame of the ANEMOS project on short-term wind power forecasting. The aim of the project is to develop accurate models that substantially outperform current state-of-the-art methods, for onshore and offshore wind power forecasting, exploiting both statistical and physical modeling approaches. The project focus on prediction horizons up to 48 hours ahead and investigates predictability of wind for higher horizons up to 7 days ahead useful i.e. for maintenance scheduling. Emphasis is given on the integration of high-resolution meteorological forecasts. For the offshore case, marine meteorology is considered as well as information by satellite-radar images. An integrated software platform, 'ANEMOS', is developed to host the various models. This system will be installed by several utilities for on-line operation at onshore and offshore wind farms for prediction at a local, regional and national scale. The applications include different terrain types and wind climates, on- and offshore cases, and interconnected or island grids. The on-line operation by the utilities will allow validation of the models and an analysis of the value of wind prediction for a competitive integration of wind energy in the developing liberalized electricity markets in the EU.**

Keywords - **Wind power, short-term forecasting, numerical weather predictions, on-line software, wind integration.**

I. INTRODUCTION

In 1997 the European Commission adopted the White Paper on renewable energies. It sets out a Community Strategy and an Action Plan to double the share of Renewable Energies Sources (RES) in gross domestic energy consumption in the European Union from the present 6% to 12% by 2010. Under this target, the problem of integration of RES and namely of wind energy in the actual energy framework is of tremendous importance.

Wind energy is one of the RES with the lowest cost of electricity production and with the largest resource available. Wind power technologies are presently mature enough to represent a major contribution. The projection of the European Wind Energy Association EWEA, for installed wind capacity by the Member States at horizon 2010 is 60 GW, while this target was recently updated upwards.

The large-scale integration of wind power in any type of power system, interconnected or autonomous (i.e. islands), imposes a number of difficulties to the power system operation. This is due to the intermittent nature of wind generation that operators need to balance, for example, by allocation of spinning reserve. The requirement for a secure and reliable operation of the power system acts as a limiting factor for wind penetration.

Experience from countries that witness today considerable wind integration shows that advanced tools are necessary to assist end-users such as utilities, independent power producers, or transmission system operators to the management of wind generation. Accurate and reliable forecasting systems of the wind production are widely recognized as a major contribution for increasing wind penetration.

Moreover, European utilities experience today restructuring in the landscape of electricity generation, transmission and distribution. The evolution towards deregulation is supported by appropriate legislative and financial frameworks that permit to new actors to enter the electricity market. However, for the case of wind energy, the intermittence of the resource limits the competitive advantage of wind production compared to dispatchable conventional electricity. The availability of accurate predictions of wind production for the next hours permits to reduce penalties in a spot market coming from over- or underestimation of the production. As a consequence, the economic attractiveness and acceptability of wind power is increased. Higher financial and operational benefits enable further investments on wind power installations.

Under this general context, the ANEMOS project was launched by pioneer research institutes in the area and end-users, in order to develop wide research and advanced solutions for onshore and offshore short-term wind power forecasting.

The prediction tools developed within ANEMOS are expected to contribute to an optimal, from the technical and economic point of view, integration of wind power in European interconnected and islands systems. The assessment of wind predictability in the project permits to further define appropriate storage systems to operate in parallel to wind farms, or appropriate management strategies, to balance the intermittence of wind resource.

Nowadays, several tools [1] have been developed for wind power forecasting (i.e. Zephyr, Predictor, Previento, WPPT, More-Care, Sipreolico and others), some of which by the partners of this project. They focus on onshore applications and are based either on physical (detailed terrain representation, roughness etc) or statistical modeling (i.e. black-box models based only on data). Physical modeling benefits from advances in the area of wind resource assessment. The project gives the possibility to advance towards both statistic and physical modeling, but also to examine in detail combination of the two approaches, which is expected to outperform each single one in several cases.

A wind power forecasting tool is composed by an ensemble of modules (downscaling, power curve modelling, model output statistics, etc), each one expected to have a good performance, in order to achieve an acceptable global accuracy. The software requirements become more complex when the aim is to predict wind power at a regional or even a national level. The project develops research over a wide spectrum of functions, which will be implemented in the form of modules and integrated in a software platform, called ANEMOS, able to operate on-line.

In order to be applicable in a wide range of applications, the Anemos platform will be developed following a detailed specification and pre-standardisation procedure by industrial partners. The architecture of the forecasting system will be modular in order to permit combination of different models for an optimal global accuracy. It will also give the possibility to run in parallel alternative models in order to increase the reliability of wind prediction. This can be a major requirement in cases of large geographical concentration of wind power like is often the case of offshore wind parks

The paper presents the structure of the project, the main axes of research and the complementary consortium set up to carry out the technical objectives.

II. DESCRIPTION OF THE PROJECT.

The project is structured into nine work-packages (WP), which address the technical objectives:

- Data collection & evaluation of needs (WP-1).
- Off-line evaluation of prediction techniques (WP-2).
- Development of statistical models (WP-3).
- Development of physical models (WP-4).
- Offshore prediction (WP-5).
- Anemos prediction platform development (WP-6).
- Installation for on-line operation (WP-7).
- Evaluation of on-line operation (WP-8).
- Overall assessment and dissemination (WP-9).The following Paragraphs present the main issues developed in the various work-packages.

1. Detailed evaluation of needs of end-users.

At a first stage of the project several audits with various actors like utilities, transmission or distribution system operators (TSO/DSO), independent power producers (IPP), regulatory authorities, etc., took place, with the aid of appropriate questionnaires, in order to evaluate requirements related to wind power prediction. Emphasis was given on the experience (confidence, level of use, etc) of actual users of forecasting tools. The results were synthesized to an "end-users requirements" report that consists a basic guideline for the developments in the project.

This part of the work develops also a detailed review of the state-of-the-art on short-term wind power forecasting. A report is produced reviewing more than 120 related publications. This document is available at the web site of the project [2]. A summary of this work is also presented in [1].

Apart from the state-of-the-art on wind power prediction, a survey of meteorological forecasting systems takes also place.

2. Benchmarking of wind power forecasting models.

During the first phase of the project a detailed evaluation of a number of base-line models will be performed including:

- AWPPS (Armines Wind Power Prediction System).
- Prediktor (RISOE)
- Zephyr/WPPT (RISOE/DTU)
- Previento (U. Oldenburg)
- LocalPred (CENER, CIEMAT)
- Sipreolico (UC3M/REE)
- Prediction model of NTUA
- Prediction system of RAL
- Prediction model of ARIA.

These models will be tuned on real data from a number of case studies from Spain, Germany, Denmark (including an offshore one), Ireland, Greece and France. The case studies are selected to correspond to different terrain types and climatic conditions. The consideration of the above base-line models will permit to identify the advantages and the limits of each approach, and the areas of improvement. At a later stage, the evaluation process will be extended to the models developed within the project.

A well-defined benchmarking framework is developed for this evaluation focusing on different time scales (e.g. short-term up to 6 hours or longer term up to 48 hours), on different criteria etc. Appropriate error measures are selected for the evaluation of the methods with emphasis to their performance in extreme weather conditions as well as their robustness in on-line environment. Experience shows that common measures, such as Root Mean Square Error, are not sensitive enough to properly indicate the prediction quality.

Part of the uncertainty in the predictions comes from the error in Numerical Weather Predictions (NWP). In parallel to the evaluation of the prediction models, forecasts generated by different meteorological systems (Hirlam, Skiron, Aladin, Mesonh, LokalModel) will be compared for the case of two wind farms corresponding to different climatic conditions. This is an original part of the work expected to give much insight on the role of NWPs in wind power forecasting.

3. Development of advanced methods for wind power forecasting.

The project develops models for forecasting wind power based on advanced statistical and physical methods.

Statistical methods (i.e. artificial intelligence based ones) permit to combine various types of explanatory input like wind direction, wind speed from neighbor sites, meteorological forecasts etc. Depending on the form of meteorological forecasts, methods for power curve modeling or statistical downscaling, giving the relationship between wind power and local forecasts for meteorological variables, are developed. Emphasis is given on outstanding problems of timeseries forecasting such as structure optimization of the models, generalization, robust learning algorithms, on-line adaptation, erroneous input, outliers a.o.

Regarding physical modeling, nowadays research is initiated on the use of Computational Fluid Dynamics (CFD) as a mean for accurate 3D wind field modeling over complex terrain. Such advanced modeling will be adapted for the case of wind prediction using as input high-resolution meteorological information. CFD modeling is an appropriate tool for scales in the order of a wind farm (e.g. 5 x 5 km) or a wind turbine (<1 km).

The contribution of high-resolution meteorological information by models such as MM5, RAMS compared to lower resolution models will be evaluated. A better description of stability in lower atmospheric boundary layer is necessary, while thermal stratification has to be modeled accurately to improve algorithms for calculating wind speed at hub height. Data from several large masts will be available in the project to investigate wind profile for different stability situations.

A promising area, where work is planned, is on the combination of statistical and physical models. Taking into account the advantages and the limitations of each type of models, the combined approach permits to obtain optimal results over the whole prediction horizon.

Finally, both statistical and physical approaches are developed both for single wind farm forecasting as well as for regional or national wind forecasting (upscaling).

4. *Prediction for offshore wind parks*

Nowadays, no specific prediction systems are available for offshore wind farms, where important installations are expected in the next years.

Meteorological conditions over sea are poorly modeled in current numerical prediction systems and mainly stability of marine atmospheric boundary layer and interaction between wind and waves have to be modeled in greater detail to allow reliable wind power predictions offshore. The stability will be investigated using measured data from met masts in the sea.

Emphasis will be given on modeling spatio-temporal characteristics in large offshore wind farms. Typically such wind farms are erected in large arrays of turbines extending over several square kilometers. This task aims to study shadowing and dynamic behavior of the wind farm under different wind conditions, e.g. when a front crosses the wind farm.

The cut-in and cut-out behavior of the machines according to their position in the farm has to be considered in connection to high-resolution meteorological information and on-line data. The consideration of other sources of information like satellite images, currently used for the evaluation of the offshore resource, are examined.

5. *Development of methods prediction risk assessment.*

Spot predictions of the wind production for the next 48 hours at a single wind farm or at a regional/national level are a primary requirement for end-users. However, for an optimal management of the wind power production it is necessary to provide end-users with additional tools for on-line assessment of the associated prediction risk.

The project gives emphasis to the development of modules for estimating the uncertainty during on-line operation. It also develops risk indices that can be used in parallel to the predictions to indicate situations where high uncertainty is expected. Such situations can be related to the weather situation. Risk indices are expected to be very useful complementary tools for trading wind production in a spot electricity market.

6. *Longer term predictions (up to 7 days).*

A specific task of the project will investigate predictability of wind power for longer-term horizons up to 7 days ahead. Such forecasts, for which there is limited experience today, are useful for example for maintenance planning.

7. *Forecasting software platform.*

Based on detailed definition of the end-user requirements, an advanced on-line software platform (ANEMOS) is under development to host the various models developed by the partners. In an off-line mode, the platform will be used for a detailed evaluation of the various models.

The ANEMOS platform will be able to provide optimal predictions under different input data cases and it will also give an estimation of the uncertainty of these predictions. The platform will integrate the most promising new models developed in the project by the partners. Modules for statistical or physical prediction, for model output statistics, for downscaling and upscaling, for online estimation of uncertainty and prediction risk a.o. will be integrated. The ANEMOS shell will have also the possibility to host existing base-line models developed by the partners through appropriate interfaces. Moreover, it will permit the implementation and on-line operation of combined (i.e. physical and statistical) models.

The shell will incorporate an advanced Man-Machine interface and a relational database for efficient data exchange and management.

Moreover, it will be enhanced with advanced Information and Communication Technology (ICT) capabilities for enabling distant use. Advanced communication interfaces will permit the developers of the software modules to access the prediction platform from a distance. The application of forecasting modules to a new site requires considerable engineering effort for tuning. Distant tuning and evaluation are useful in the case of a large-scale application of forecasting tools.

Hence, the Anemos will platform provide access to a portfolio of plug-&-play modules available locally or remotely (through internet) and covering a wide range of

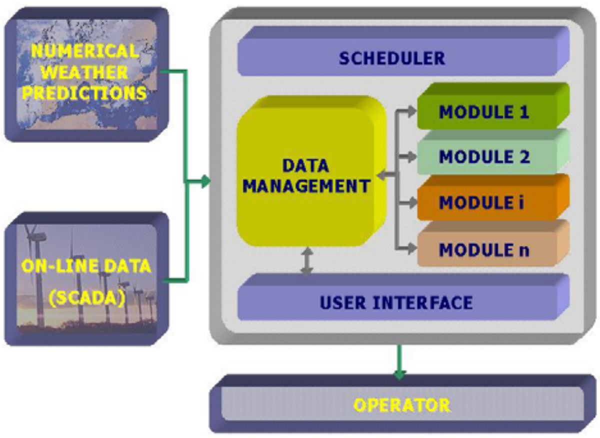

Fig. 1: *General architecture of the ANEMOS prediction platform.*

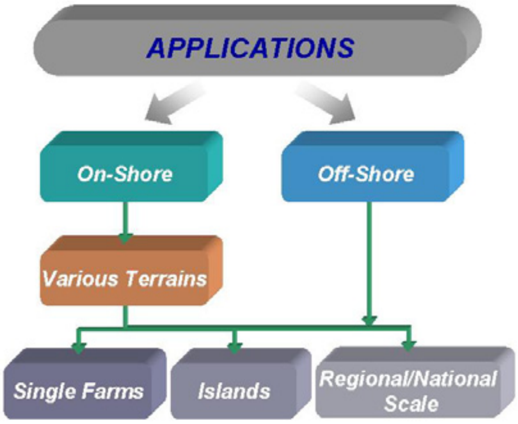

Fig. 2: *A wide range of on-line applications is planned for detailed evaluation and optimal exploitation of the results.*

requirements. A potential user will be able to select the most appropriate ones and tailor the prediction platform to a specific application. Potential users of the platform can be IPPs, Energy Service Providers that may use the platform as a Prediction Service; utilities, TSOs, DSOs and others.

8. *Installation on onshore and offshore cases.*

The on-line platform will be installed for online operation to a number of onshore and offshore sites. The sites are selected among the participants EDF, EHN, ELSAM, EWE, ESB, IDAE and PPC. On-line installation will be followed by an extensive evaluation phase.

The installations cover a wide range of characteristics ranging from interconnected to island systems, various terrain types, onshore, near-shore and offshore wind parks and for single wind farms or regional/national wind power (Fig 2).

9. *Evaluation of benefits from wind prediction*

The above range of applications will permit to evaluate in detail the performance of the models developed within the project under various operating conditions. The benefits by the use of a forecasting model will be estimated in two levels: by the use of specific models that simulate the operation of a power system in detail. By this way the monetary value of the forecasts can be estimated (i.e. due to fuel savings) but also their influence to the security of the system. Benefits will also be evaluated from the end users (utilities, wind farm owners etc.) point of view. Relations with existing projects that use wind power forecasts will be established (e.g. More-Care project). The influence of forecasts on aspects like system stability, definition of penetration limits, pollution prevention will be assessed etc**.**

Finally, emphasis will be given on analyzing the correlation between prediction uncertainty and electricity prices and how to develop optimal strategies for wind power participation in electricity market.

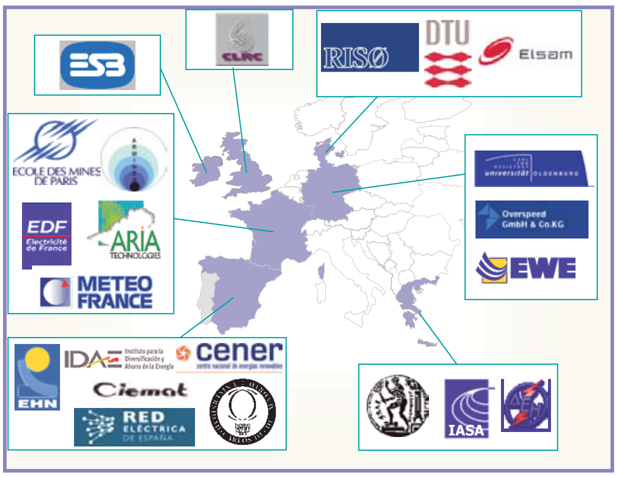

Fig. 3: *The project Consortium.*

III. The Consortium

In order to achieve the challenging targets of the project, a Consortium from seven countries has been set-up integrating major actors from complementary areas including research institutes, universities, industrial companies, utilities, transmission system operators, meteorological institutes and energy agencies – Fig 3.

IV. Conclusions

The project provides an advanced technology for wind power forecasting applicable on a large scale: at a single wind farm, regional or national level and for both interconnected and island systems. A next generation forecasting software, ANEMOS, is under development to integrate a variety of modules covering a wide range of requirements for wind prediction and uncertainty estimation. The platform will be enhanced by advanced Information & Communication Technology functionality and will be able to operate both in stand alone or remote mode, or be interfaced with standard Energy Management Systems. The software will be installed for on-line operation at a number of onshore and offshore wind farms. The benefits will be evaluated during on-line operation, while guidelines will be produced for the optimal use of wind prediction systems.

The output of the ANEMOS project is expected to facsilitate wind power integration at two levels. Firstly, at an operational level, since it will allow better management of wind farms and more efficient participation of wind production in the electricity markets. Secondly, 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.

V. Acknowledgment

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VI. References

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