Advanced Short-term Forecasting of Wind Generation - Anemos.

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Abstract— **Accurate forecasting of wind farms power 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. As wind integration increases, the requirements for wind power forecasting diversify depending on the end-user and the context. In the frame of the EU project Anemos multidisciplinary research has been carried out in wind forecasting by a number of research organizations and end-users with wide experience in the field. Advanced statistical, physical and combined modeling approaches were developed including methods for on-line uncertainty and prediction risk assessment. An integrated software platform was developed to host the various models. It was installed by several end-users for on-line operation and evaluation at a local, regional and national scale. This paper presents the research methodology and the major results obtained.**

Index Terms—**Short-term wind power forecasting, uncertainty, numerical weather predictions, online 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 particularly 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 now mature enough to represent a major contribution. The projections of the European Wind Energy Association EWEA, for installed wind capacity in the EU 15 by 2010 and 2020 are 75 GW and 180 GW respectively.

The large-scale integration of wind power in any type of power system, interconnected or autonomous (i.e. islands), imposes a number of difficulties on power system operation. This is due to the fluctuating 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 currently possessing 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 are currently witnessing restructuring in the landscape of electricity generation, transmission and distribution. The evolution towards deregulation is supported by appropriate legislative and financial frameworks that permit new players to enter the electricity market. However, for the case of wind energy, the variability of the resource limits the competitiveness of wind production compared to dispatchable conventional electricity. The availability of accurate predictions of wind production few hours into the future permits a reduction in penalties in a spot market coming from over- or underestimations of the production. As a consequence, the economic attractiveness and acceptability of wind power is increased.

In this general context, the R&D project ANEMOS was launched in October 2002 by pioneer research institutes in the field and end-users, in order to carry out wide-ranging research and develop 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

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economic point of view, integration of wind power in interconnected and islands systems. The assessment of wind predictability and uncertainty in this project permits to further define appropriate storage systems or reserve requirements 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. Prediktor, Previento, WPPT, More-Care, Sipreolico, AWPPS, and others), some of them 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- or grey-box models based only on data). Physical modeling benefits from advances in the area of wind resource assessment. The aim here is to advance towards both statistic and physical modeling, but also to examine in detail combination of the two approaches, which is generally expected to outperform the individual cases.

A wind power forecasting tool is composed of several modules (downscaling, power curve modeling, model output statistics, etc), each one expected to have a good performance, in order to achieve an acceptable overall 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 developed research over a wide spectrum of functions, which are implemented in the form of modules and integrated in a software platform, called ANEMOS, able to operate online.

In order to be applicable in a broad range of applications, the ANEMOS platform was developed following a thorough specification and pre-standardization procedure by industrial partners. The architecture of the forecasting system is modular in order to permit parallel operation of alternative models and combination of their predictions for a high reliability and an optimal global accuracy.. This can be a major requirement in cases of large geographical concentration of wind power such as is often the case in offshore wind parks.

II. THE ANEMOS APPROACH

The project is structured into nine work-packages, which address 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.

A. *Detailed evaluation of needs of end-users and state-of-the art review.*

At a first stage of this work several audits with various players such as utilities, transmission or distribution system operators, independent power producers, regulatory authorities a.o., 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.) end-users have with existing forecasting tools. The results were synthesized to an “end-users requirements” report that consists a basic guideline for the developments in the project.

In addition, a detailed survey of the literature on wind power forecasting was performed with the review of more than 120 references [1].

B. *Benchmarking of wind power forecasting models.*

Initially, a detailed evaluation of a number of base-line forecasting systems (and some versions of them) was performed [4] including:

- AWPPS (Ecole des Mines/Armines).
- LocalPred (CENER, CIEMAT)
- Prediktor (RISOE)
- Previento (Univ. Oldenburg, EMSYS)
- Sipreolico (UC3M/REE)
- WPPT (DTU/IMM)
- Prediction model of NTUA
- Prediction model of RAL
- Prediction model of ARIA.

These models were tuned on real data from a number of case studies in Spain, Germany, Denmark (including an offshore one), Ireland, France and Greece. The case studies were selected to represent different terrain types and climatic conditions. The consideration of the above base-line models permitted identification of the advantages and the limitations of each approach, and the areas for improvement. A clearly-defined benchmarking framework was 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 [2]. File exchanges were performed through a secured web site. Appropriate error measures were 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. The different modeling approaches were evaluated in a virtual laboratory (see Fig. 1).

Fig. 2 shows a representative result of this comparison. The normalized mean absolute error (NMAE – normalization with wind farms nominal capacity) is depicted for 6 wind farms as a function of the terrain complexity. This latter is expressed by the RIX index [3], which reflects the slope of the terrain around the wind farm.

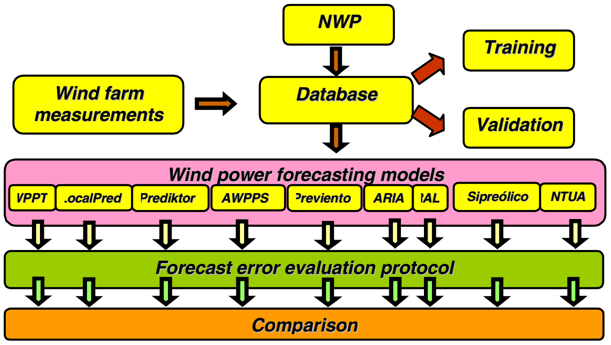

Fig. 1. *Design of the virtual laboratory set-up for the models benchmarking.*

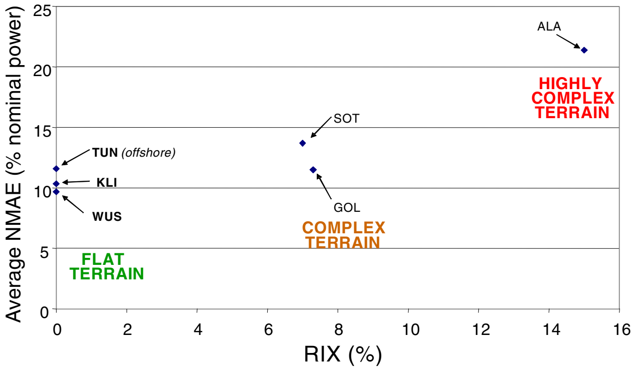

Fig. 2. Average NMAE for 12 hours forecast horizon vs RIX at each test case. Qualitative comparison. TUN is an offshore wind farm in Denmark, KLI is also located in Denmark, WUS in Germany, GOL in Ireland and ALA and SOT in Spain.

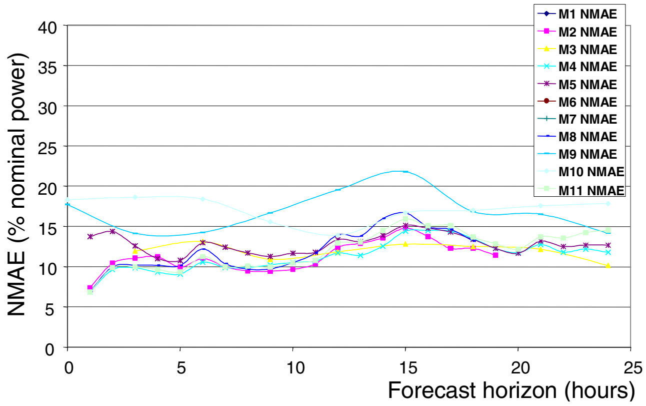

Fig. 3. Comparison of the performance of 11prediction models (M1-M11) on the Sotavento wind farm in Spain (complex terrain). The NMAE is given as a function of the prediction horizon which here is 24 hours ahead.

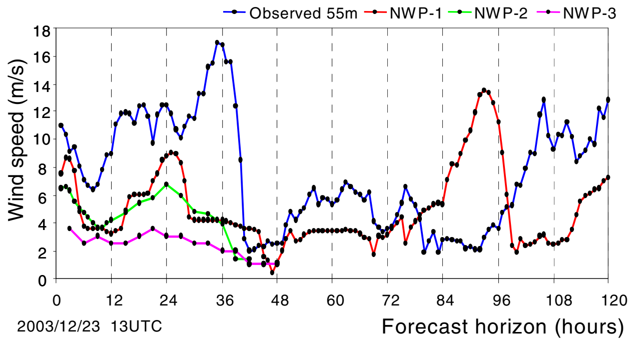

Fig. 4. Comparison of wind speed measurements (at 55m – blue line) to NWPs (at 10m) provided by 3 different meteorological models for a complex terrain wind farm site.

Each value in Fig. 2 is the average of the NMAE performance obtained by the 11 models. The figure illustrates well how the performance is a function of the terrain. It gives also the level of predictability for single wind farm prediction. It is noted that predictability is better when wind production is predicted on a regional basis as a result of the spatial smoothing effect from the geographical distribution of the wind farms [6].

Fig. 3 shows a comparison of the performance of the various physical and statistical models on a test case in Spain (SOT) as a function of the prediction horizon.

Part of the uncertainty in the wind power 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, etc) were compared for the case of two wind farms corresponding to different climatic conditions – example in Fig. 4. This is an original part of the work that provides much insight on the role of NWPs in wind power forecasting [4], [5].

C. Short-term forecasting using advanced physical modeling.

In this work focus was given to challenging situations like prediction of wind farm output at complex terrain sites. A possible solution to that problem comes in the form of high-resolution, advanced numerical flow models trying to improve on the NWP models shortcomings [7].

These models can be linear flow models like Risø's WAsP, or AriaWind, meso-scale models like the well-known MM5 community model, MeteoFrance's MesoNH or IASA's RAMS model, or full-blown CFD models (Computational Fluid Dynamics) like Fluent or Mercure.

The idea of all models is the same: use higher resolution calculation and input data bases plus a more complete physics descriptions than the NWP model to try to capture the local air flows, be it in the mountains or at a land-sea border – see Fig. 6, Fig. 7. Whereas NWP models typically have a horizontal resolution of 5-10 km, the meso-scale models employed here can go down to 500 m.

The new approaches were tested at three sites: Alaiz, a complex terrain site in northern Spain, Ersa-Rogliano, a two-cluster wind farm on the narrow tip of Corsica, and four wind farms at the eastern end of Crete.

For MM5, several Planetary Boundary Layer parameterizations were tried out, and it was found that the Blackadar scheme did not perform as wellas the MRF or ETA PBL schemes. The last degree of horizontal resolution might not be necessary, the same accuracy can be gained with a larger finest nested area. A higher number of vertical levels in the lowest 100m above the surface helps. MM5 could improve on the simple HIRLAM forecasts in Alaiz. The accuracy of the MM5 forecasts seems to depend a lot on the accuracy of the driving model (NCEP 6-hourly or GFS hourly).

KAMM could explain the turning effects of the wind (see Fig. 5) for the Spanish test case. A domain size of 400 km x 400 km was needed. However, a MOS system (where data is available) might do as well [7].

For RAMS in Corsica and Crete, the second model level (46m a.g.l.) performed usually better than the 10 m wind. Using 500 m horizontal resolution helped here (probably due to the much better orography description used in comparison to MM5).

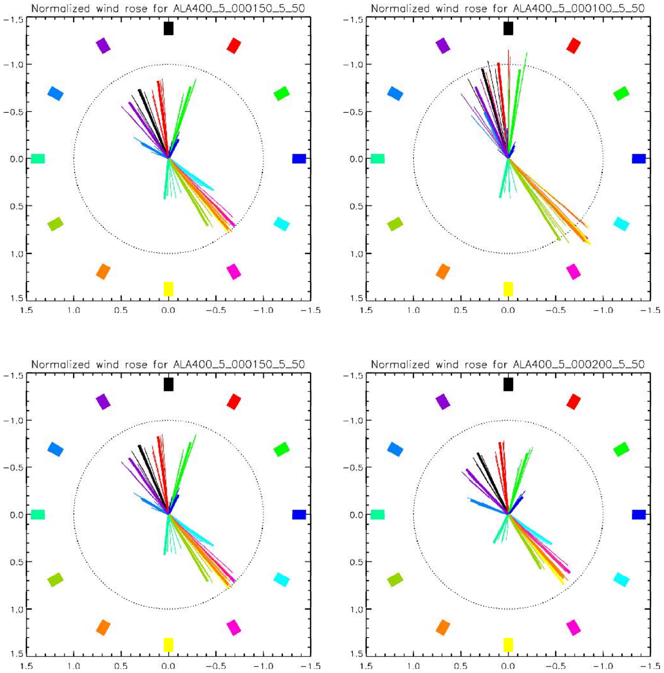

Fig. 5. The wind speed enhancement and turning effect of the topography are dependent on the wind speed, profile and stability configurations. These effects are displayed in the above diagrams showing the mesoscale effect on the geostrophic wind forcings.

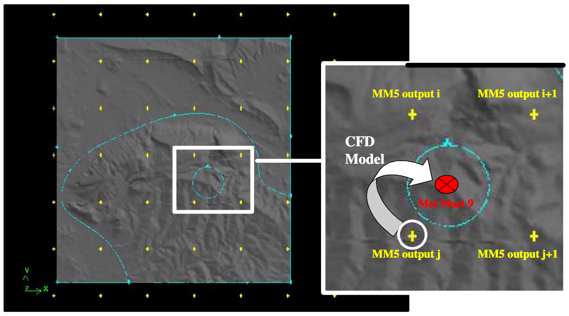

Fig. 6. CFD downscaling of MM5 NWP. 3D view of the area at Alaiz wind farm in Spain and MM5 grid.

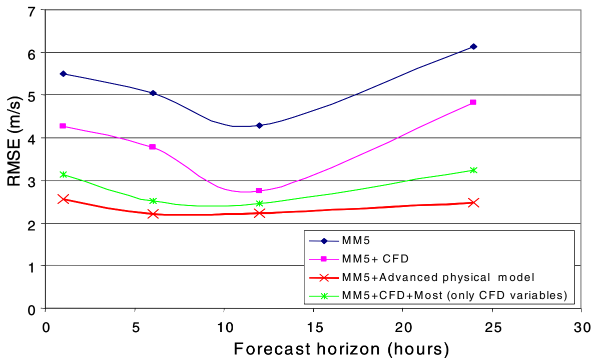

Fig. 7. Comparison of Root Mean Square Error (RMSE) of wind speed forecasts for Alaiz wind farm using MM5, MM5+CFD, MM5+an advanced physical model, MM5+CFD+MOS (only CFD variables).

In general, the models revealed the problem of representativity of a single measurement for a whole region. We are comparing model output valid for an area with a measurement in one particular point. Another issue which has to be solved on a case by case basis is whether the computational effort required is justified.

D. Advanced statistical modeling and uncertainty assessment.

A first topic of research in statistical modeling was to develop approaches for post-processing NWPs in order to reduce systematic errors. For example, a new way of encapsulating non-linear dynamics in the Kalman filter was developed and applied to improve NWPs data and in particular wind speed [14]. This permitted to reduce up to 20% the error of power predictions as shown in Fig. 8.

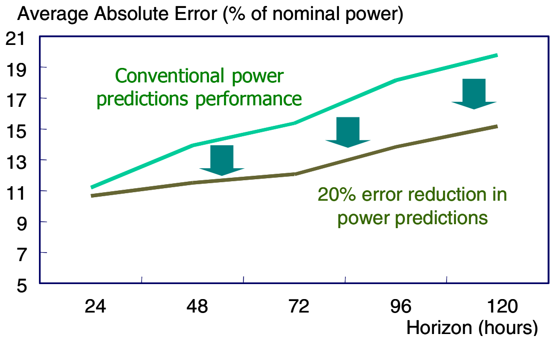

Fig. 8. Improvement on the performance of power predictions by using the Kalman approach to filter NWPs.

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, a.o (i.e. [14]-[16]). These techniques permit combination of various types of explanatory input variables like wind direction, wind speed from neighbor sites, numerical weather predictions etc.

A topic of research was power curve modeling where approaches based on neural networks, fuzzy logic and local regression were evaluated. Such models aim to describe the relationship between local power production and local meteorological measurements or forecasts - Fig. 9. Experience so far shows that one of the main error sources in wind power prediction lies in insufficient power curve modeling. The use of certified power curves does not guarantee that the relation between wind speed and power output is in practice accurately described.

Work on statistical downscaling aimed at developing models describing the dependency between meteorological forecasts from nodes surrounding a location (the global wind field) and local observations. Statistical downscaling can here be seen as an alternative technique to explicit terrain and roughness modeling.

Emphasis was given to developing upscaling approaches for predicting regional/national wind power production from a sample of wind farms for which power predictions are available. The cases of Jutland/Funen in Denmark and EWE in northern Germany, each in the order of 2200 MW and in Ireland, were used for evaluation [6]. The results show that, due to the smoothing effect, forecast accuracy is higher for regional forecasting than for individual wind farm forecasting. The average error for 24 hours ahead for Jutland is 6.2%.

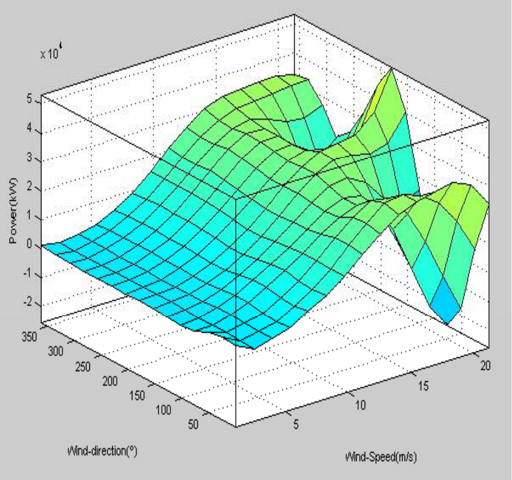

Fig. 9. A two dimensional power curve model based on fuzzy-logic approach for the Alaiz wind farm in Spain (very complex terrain) [17].

A priority theme of the project concerned uncertainty. Initially, a characterization of prediction errors was performed [6]. Methods for assessing the situation-specific uncertainty in the power predictions have been developed able to provide prediction intervals for pre-selected confidence levels – see [6], [8]-[10]. Furthermore, prediction risk methods were developed to use 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 are a complementary tool to prediction intervals. It is a means to "forecast" the level of uncertainty – see Fig. 12. I.e. when a high value of the risk index is provided for the next day, the operators may adapt their strategies by taking preventive actions like higher spinning reserves.

E. *Short-term forecasting of offshore wind farms production*

Although much experience exists for onshore wind farms modeling and prediction, this not the case for offshore [19]. Here emphasis was given to high-resolution marine meteorological forecasts and the analysis of different meteorological conditions offshore. The sea surface roughness is very low, and the thermal stratification of the atmosphere, i.e. the thermal stability of the wind flow, is for long periods very different from the near neutral case observed onshore.

Additionally, the low roughness increases the influence of stability on the wind speed profile. The project investigated the most important parameters which influence the wind speed profile offshore. Pure numerical meteorological forecasts were compared with measured time series from several sites.

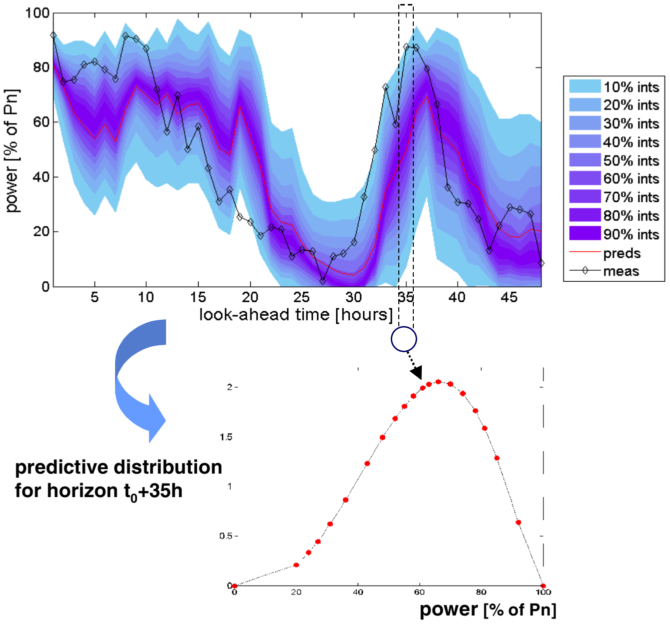

Fig. 11. Example of forecasts for the next 48 hours compared to measured values. Prediction intervals for various levels of confidence are displayed. Intervals are estimated with the adapted resampling approach.

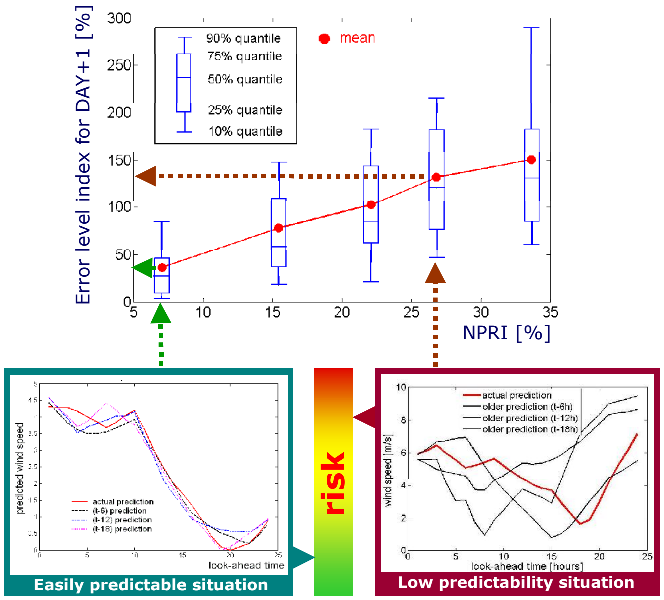

Fig. 12. Translation of weather predictability to power predictability for next day using the Normalized Prediction Risk index (NPRI). Bottom-left: the alternative predictions for the next day are very similar resulting in a high degree of confidence. Bottom-right: the alternative predictions differ significantly – this lowers the confidence in the future weather predictability. Each situation is represented by a value of the risk index. Though 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).

A new air-sea-interaction model for calculating marine wind speed profiles was developed, i.e. the theory of inertially coupled wind profiles (ICWP). The model is based on inertial coupling of the wave-field to a wave boundary layer with constant shear stress which is matched to the Ekman layer of the atmosphere. Evaluation with Horns Rev (Fig. 13) and FINO1 data [11] showed good agreement, especially regarding wind shears.

Next, emphasis was given to modeling spatio-temporal characteristics in large offshore farms [20]. New approaches were developed to model wakes behind such farms. Wake losses are anticipated to be at least 5-10% of power output. Wind speed recovery can be predicted to occur between 2 and 15 km downwind of such farms according to the model type chosen. A new whole wind farm model was developed (Storpark) based on conserving momentum deficits. Also, comparison of mesoscale model results with WAsP predictions was performed to quantify gradients of wind speed over large wind farms. These gradient corrections were compared with corrections needed for vertical wind speed profiles and for wake losses in order to identify which have the largest impact on power output on a case by case basis.

A new module for FLaP, which is the wake-model from Oldenburg University, was developed. The underlying Ainslie-model is based on eddy viscosity closure of the Reynolds equations with a boundary layer approximation and leads to a modified Gaussian distribution of speed losses. The turbulence intensity profile in the wake is now modeled with the Magnusson-formula, which improves the calculation of added turbulence.

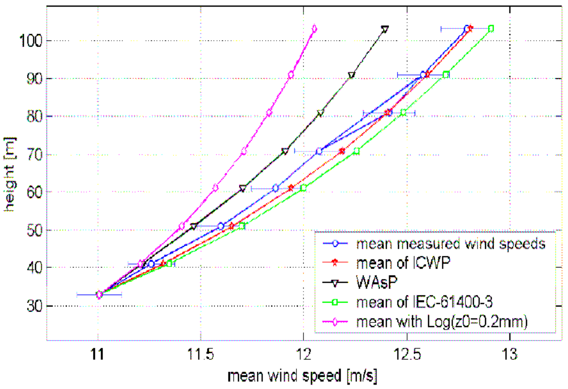

Fig. 13. Mean measured “open sea” sector (135°-360°) wind profile at Horns Rev compared to mean of ICWPs and average offshore WAsP profile. Period 10/2001-04/2002.

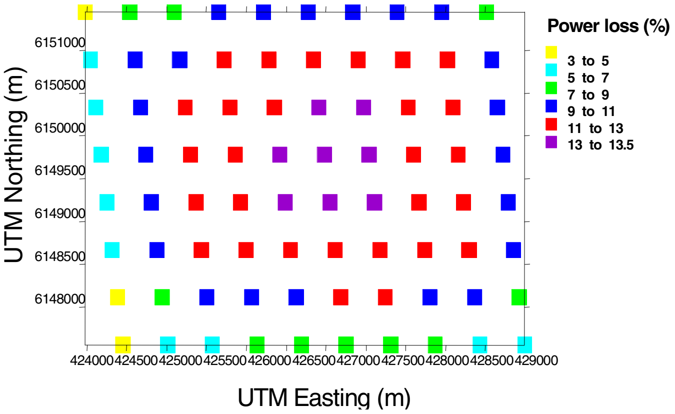

Fig. 14. Evaluation of wake effect in a large offshore wind farm. Total wakes power loss is ~10% but individual wake losses are much larger.

A study was performed on the regional forecast for a total capacity of 25 GW in the German Bight, which showed a Root Mean Square Error (RMSE) of 9-17, credited to spatial smoothing effects that reduce the error by a factor of 0.73 compared to a single site [22]. Hence, a combined regional forecast for all offshore sites would show an RMSE of 12% at 36 hour forecast time, i.e. an absolute RMSE of 3 GW. It was then of interest to estimate the respective spatial error smoothing for the sum of onshore and offshore wind farms in Germany. An aggregated forecast for a situation with 25 GW installed offshore capacity and 25 GW onshore for the year 2004 was calculated. The sum of the offshore wind power time series calculated from the weather analysis and the real German onshore wind power production time series from 2004 that was scaled from 17 GW to 25GW was used as reference. The resulting RMSE ranges from 5% to 10% (Fig. 15), i.e. the area size of 800 km leads to an error reduction

In a dedicated task, the potential contribution of satellite data in offshore prediction was studied.

Finally, various physical (i.e. MM5) and statistical (i.e. neural networks) models were calibrated on power data from two offshore wind farms: Tunoe and Middelgrunden in Denmark. Performance was comparable to onshore results.

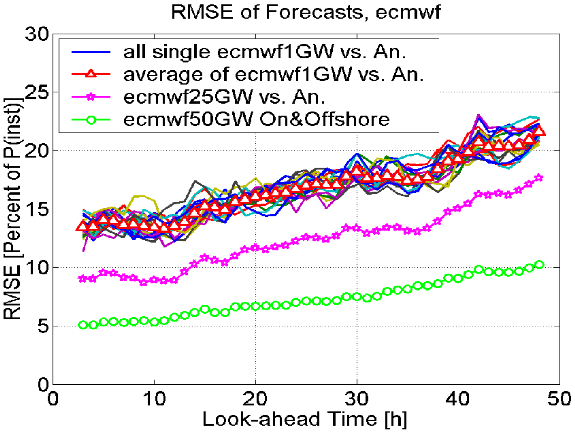

Fig. 15. RMSE of ECMWF wind power forecasts. Thin lines: all single 22 sites. Red triangles: Average of single sites. Pink stars: Aggregated 25 GW offshore forecast. Green circles: Aggregated 50 GW on-&offshore forecast.

F. The ANEMOS forecasting platform.

Today wind power prediction is an operational, commercial task which must fit into the requirements of ambitious customers like utilities, TSOs and operators of large wind farms. Although being operationally feasible, many approaches for power forecasting originated from research environment.

In the framework of the ANEMOS project, a professional, flexible platform was developed for operating wind power prediction models, laying the main focus on state-of-the-art IT techniques, inter-platform operability, availability and safety of operation. Currently, several plug-in prediction models from all over Europe are able to work on this platform. They cover a wide range of end-user requirements such as short-term prediction (0-6 hours) by statistical approaches, medium term prediction (0-48/72 hours) by statistical and physical approaches, combined approaches, regional/national forecasting through upscaling techniques, on-line uncertainty estimation, probabilistic forecasts, risk assessment, multiple numerical weather predictions as input and others. The flexibility of the platform permits simple settings for single wind farm prediction up to more complex ones corresponding to large wind power capacities. It can run in a remote mode by the ANEMOS Consortium as a prediction service or be installed to run as a stand alone application.

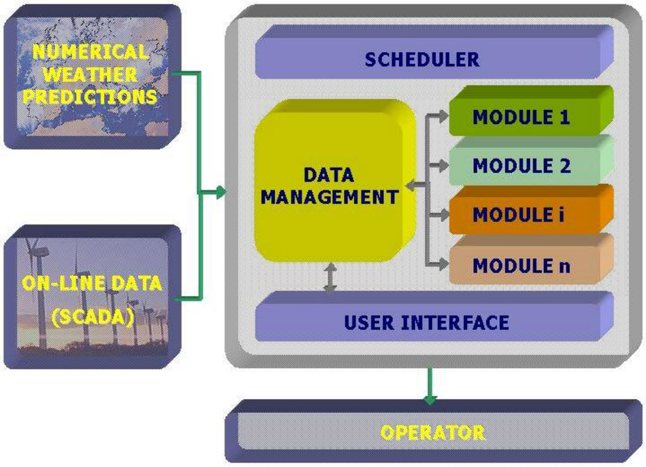

Fig. 16. General architecture of the ANEMOS prediction platform.

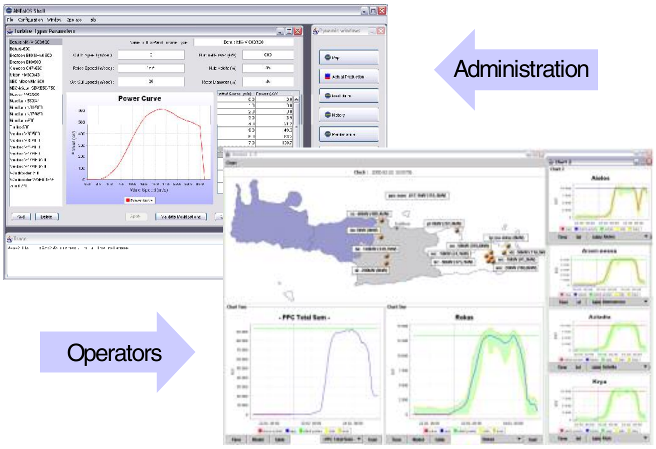

Fig. 17. Ergonomic, graphical users interfaces were developed to visualize predictions and operate the system.

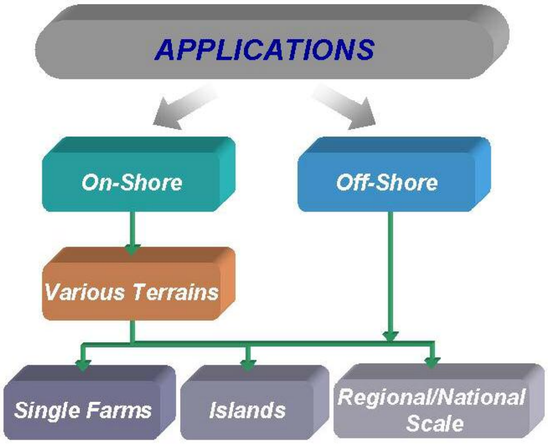

Fig. 18. A wide range of on-line applications is planned for detailed evaluation and optimal exploitation of the results.

All interfaces, data formats and data base structures are well-defined and well-documented. For the actual prediction models, different ways of data retrieval and sending are available, starting with simple but standardized file exchange up to web service interfaces. Following this approach, the integration of different models was made easy and effective for the modelers.

Also, for safe operation, an option for operation on multiple servers was implemented. By this way, it is possible to operate two or more servers at different physical locations for the same prediction tasks, with independent power suppliers and network infrastructures. These servers will automatically take over the tasks of data retrieval, production and delivery from one another if any problem occurs at one place. With this approach, we achieved a 100% availability of the prediction service in the last 18 months.

The advantages of this platform approach for wind power prediction customers are quite obvious: safe operation, high availability, easy integration in its own IT structures and access to a variety of forecasting models with only one starting infrastructure investment and a single user interface [12].

The platform is installed in 7 countries for online operation by 8 end-users including TSOs, utilities and wind farm developers. The actual installations cover applications like onshore and offshore parks, island power systems and regional/national forecasting - Fig. 18.

G. Evaluation results

In each of the above-mentioned installations, a number of wind power prediction models are activated. For some cases NWPs by alternative meteorological models are considered as input. The accuracy of the various models during on-line operation is then evaluated. Examples are shown in Fig. 14 for the cases of Alaiz wind farm in Spain (which is probably the site with the most complex terrain in the project) and Guerledan wind farm in France. The figures show the performance of various simple and advanced models that use either Hirlam, Skiron or Aladin NWPs as input. The optimal models have in fact better performance than the one found using historical data at the offline benchmarking process reported in [5].

Apart from their accuracy, it is of interest to evaluate the value of wind power forecasts for end-users. The influence of forecasts on aspects such as system stability, definition of penetration limits, pollution prevention (i.e. due to fuel saving) are addressed. Fig. 21 shows the reduction achieved in GHG emissions from using advanced wind power forecasting for the power system of Crete in Greece.

Finally, it was evaluated the correlation between prediction uncertainty and electricity prices and how to develop optimal strategies for wind power participation in electricity market. An example is shown in Fig. 22 , which shows the revenues of a wind farm resulting from its participation in an electricity market. Revenue 100% corresponds to perfect forecasting where no penalties apply for imbalances. The simple method of persistence gives the lower bound. Bidding strategies based

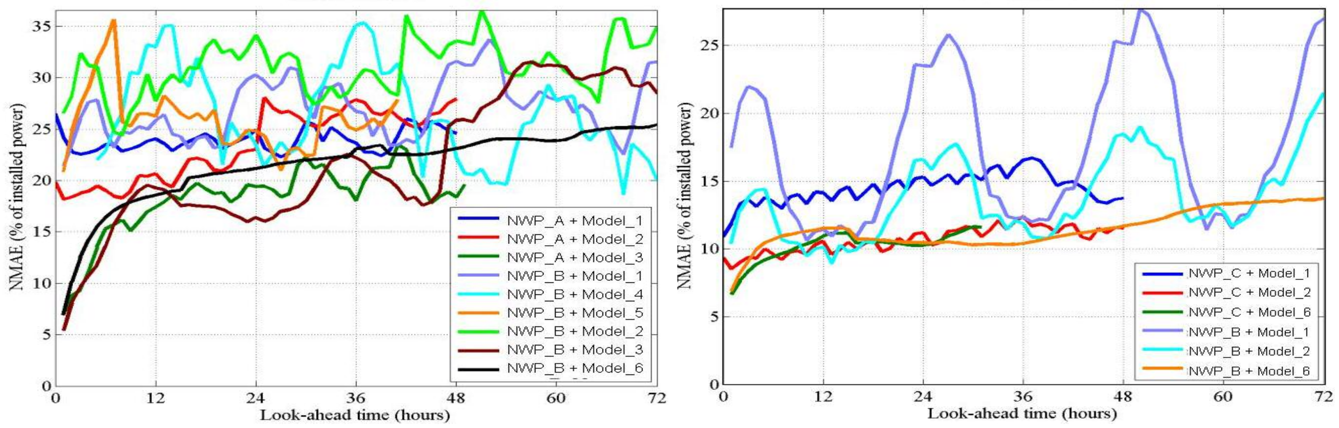

Fig. 20. Evaluation of the on-line operation of several prediction models for the Alaiz wind farm in Spain. (left figure) and Guerledan wind farm in France (right figure).

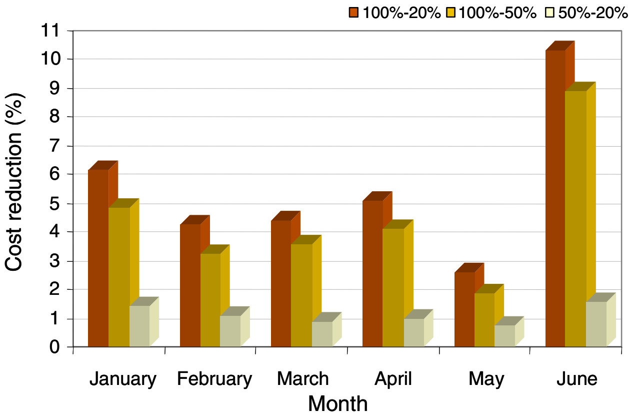

Fig. 21. Study on the power system of Crete. Estimation of monthly cost reduction due to improvement in the wind forecasts accuracy. A 6-10% reduction is achieved also in GHG emissions (SO_2, NO_X, CO_2) by the use of an advanced forecasting tool that permits to avoid excessive reserves allocation.

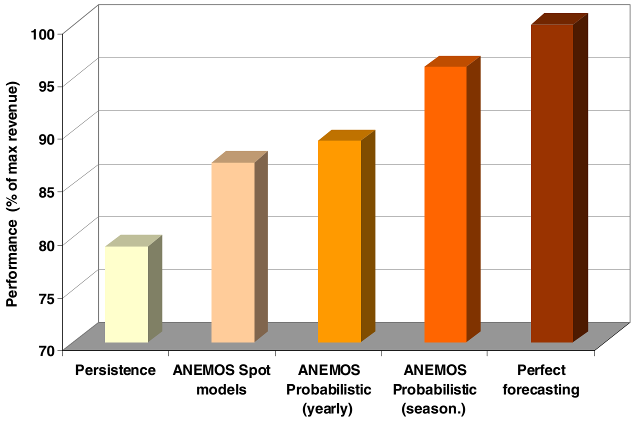

Fig. 22. Evaluation of the revenues obtained from the participation of a wind farm in an electricity market.

on the uncertainty information allow the benefits compared to the case where only spot predictions are used to be increased.

III. CONCLUSIONS

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, was presented in this paper. For detailed information on the results of the project, a list of selected references is given at the end of the paper.

A next generation forecasting software, ANEMOS, has been developed to integrate a variety of modules covering a wide range of requirements for wind prediction and uncertainty estimation. The platform is able to operate both in stand alone or remote mode, or be interfaced with standard Energy Management Systems. The software was installed for on-line operation at a number of onshore and offshore wind farms. The benefits are evaluated during on-line operation, while guidelines will be produced for the optimal use of wind prediction systems.

After running four years of the project, it is worth mentioning that the large size of the consortium has been extremely beneficial. It permitted to establish a high degree of synergy between experts from various fields. It led to achievements that would have been very difficult for single partners or smaller groupings to realize. It permitted an accurate 'mapping' of the wind forecasting technology useful for developing grid and market regulations. Moreover, having together end-users with different perspectives regarding wind prediction, resulted in a clear view regarding requirements and priorities. Last but not least, it permitted data base of valuable information (i.e. measurements) for extensive validations of the modeling work to be created. The project has globally contributed to improving forecasting technology as shown below:

Prior to the project		Project contributions
Deterministic forecasting		Towards probabilistic forecasting
The classic model chain		Extension by inclusion of new solutions (combined models, multiple NWPs, ensemble predictions)
Accuracy oriented models		Accuracy + robustness + value oriented models
Research prediction tools		Standardized, pre-industrial tools.

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. In particular, the "value" relates to the integration of predictions and their uncertainty in management functions and decision making processes related to wind power. This will be one of the objectives of the follow-up project ANEMOS.plus [27].

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.

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