ANNEX I: DESCRIPTION OF WORK

DEVELOPMENT OF A NEXT GENERATION WIND RESOURCE FORECASTING SYSTEM FOR THE LARGE-SCALE INTEGRATION OF ONSHORE AND OFFSHORE WIND FARMS.

ANEMOS

PROPOSAL N° : NNE5-2001-00857

CONTRACT N° : .....

PROJECT COORDINATOR :

	1 Association pour la Recherche et le Développement des Méthodes et Processus Industriels – Centre d'Energétique.	ARMINES-CENERG	F

CONTRACTORS :

2	ARIA Technologies S.A	ARIA	F
3	Universidad Carlos III de Madrid	UC3M	E
4	Centro de Investigaciones Energeticas, Medioambientales y Technologias	CIEMAT	E
5	Technical University of Denmark	DTU	DK
6	Meteo France	METEO-FRANCE	F
7	OVERSPEED GmbH & Co. KG	OVERSPEED	D
8	Council of the Central Laboratory of the Research Councils	CCLRC/RAL	UK
9	Risø National Laboratory	RISOE	DK
10	Institute of Accelerating Systems and Applications	IASA	EL
11	University of Oldenburg	Univ-Oldenburg	D
12	Electricité de France	EDF	F
13	Energia Hidroeléctrica de Navarra, S.A	EHN	E
14	ELSAM A/S	ELSAM	DK
15	National Grid, Electricity Supply Board	ESB	IRL
16	EWE Aktiengesellschaft/Abteilung HV-BE	EWE	D
17	Public Power Corporation S.A.	PPC	EL
18	Red Eléctrica de España	REE	E
19	Instituto para la Diversificación y Ahorro de la Energía	IDAE	E
20	Institute of Communication & Computer Systems - National Technical University of Athens	ICCS/NTUA	EL
21	Ecole Nationale Supérieure des Mines de Paris-Centre d'Energétique.	ENSMP-CENERG	F

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DEVELOPMENT OF A NEXT GENERATION WIND RESOURCE FORECASTING SYSTEM FOR THE LARGE-SCALE INTEGRATION OF ONSHORE AND OFFSHORE WIND FARMS. ANEMOS

PROJECT SUMMARY

OBJECTIVES

Accurate forecasting of the wind resource up to two days ahead is recognised as a major contribution for reliable large-scale wind power integration. Especially, in a liberalised electricity market, prediction tools enhance the position of wind energy compared to other forms of dispatchable generation. The ANEMOS project aims to develop advanced forecasting models that will substantially outperform current methods. Emphasis is given to situations like complex terrain, extreme weather conditions, as well as to offshore prediction for which no specific tools currently exist. The prediction models are implemented in a software platform and installed for online operation at onshore and offshore wind farms by the end-users participating in the project. The project demonstrates the economic and technical benefits from accurate wind prediction at different levels: national, regional or at single wind farm level and for time horizons ranging from minutes up to several days ahead.

DESCRIPTION OF THE WORK

The project is structured into 10 work-packages, which address the technical objectives. Initially, the prediction requirements are defined in collaboration with end-users.

The project develops prediction models based on both a physical and an alternative statistical approach. Research on physical models gives emphasis to techniques for use in complex terrain and the development of prediction tools based on CFD techniques, advanced model output statistics or high-resolution meteorological information. Statistical models (i.e. based on artificial intelligence) are developed for downscaling, power curve representation, upscaling for prediction at regional or national level, etc. A benchmarking process is set-up to evaluate the performance of the developed models and to compare them with existing ones using a number of case studies. The synergy between statistical and physical approaches is examined to identify promising areas for further improvement of forecasting accuracy. The performance of purely meteorological forecasts, but also long-term wind predictability up to 7 days ahead, are evaluated in detail. Appropriate physical and statistical prediction models are also developed for offshore wind farms taking into account advances in marine meteorology (interaction between wind and waves, coastal effects). The benefits from the use of satellite radar images for modelling local weather patterns are investigated.

A next generation forecasting software, ANEMOS, is developed to integrate the various models. The tool is enhanced by advanced ICT functionality and can operate both in stand alone, or remote mode, or be interfaced with standard EMS/DMS systems. The software will be installed for on-line operation at a number of onshore and offshore wind farms. Finally, the benefits from wind prediction will be evaluated during on-line operation, while guidelines will be produced for the optimal use of wind forecasting systems.

MILESTONES AND EXPECTED RESULTS

The project provides an advanced technology for wind resource forecasting applicable in a large scale: at a single wind farm, regional or national level and for both interconnected and island systems. A major milestone of the project is the on-line operation of the developed software by the participating utilities for onshore and offshore wind farms. The outcome of the ANEMOS project will help consistently the increase of wind integration in two levels; in an operational level due to better management of wind farms, but also, it will contribute to increasing the installed capacity of wind farms. This is because accurate prediction of the resource reduces the risk of wind farm developers, who are then more willing to undertake new wind farm installations especially in a liberalised electricity market environment.

1. Objectives

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 power that operators need to balance, for example, by allocation of high spinning reserve to face possible variations of wind power. The requirement for a secure and reliable operation of the power system acts thus, as a limiting factor for large-scale 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 intermittent wind generation. Accurate forecasting systems of the wind resource are widely recognised as a major contribution for a large and reliable wind integration.

Especially, in a liberalised electricity market environment, the availability of accurate predictions of wind production for the next hours is a challenge, since both overestimation and underestimation will be translated to penalties. Such penalties reduce the economic attractiveness of wind power compared to conventional dispatchable electricity. The improvement of the forecasting accuracy is expected to be a major contribution to the acceptability of wind energy into power systems.

Nowadays, several tools 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. The state-of-the art tools focus on onshore applications and are usually developed under the frame of specific applications. They are based either on physical (detailed terrain representation, roughness etc) or statistical modelling (i.e. black-box type of models based only on measurements). Physical modelling benefits from advances in the area of wind resource assessment. This project will give the possibility to advance towards both statistic and physical modelling, but will also examine in detail combination of the two approaches. A combined approach is expected to outperform each single one in several cases.

A wind resource forecasting tool is composed by an ensemble of modules (downscaling, wind power curve, model output statistics, performance criteria, 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 will develop research over a wide spectrum of functions composing “wind resource forecasting”. These functions will be implemented in the form of modules and integrated in a software shell, called ANEMOS, able to operate on-line.

The development of this software within the project will be done under the objective to develop a tool applicable This modular architecture will permit to combine different models in order to achieve globally better results. 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. A detailed specifications and pre-standardisation procedure will enable the developed tool appropriate for large-scale application.

In an initial stage of the project, the modular architecture of ANEMOS software will permit to integrate forecasts produced by a number of existing (base-line) models developed by the partners, in order to evaluate and compare their performance under various operating and weather conditions. This benchmarking procedure will permit to compare models developed in the project with existing ones and save into the ANEMOS database the results in a standard way for analysis. This procedure will be beneficial both for existing tools but also for the new techniques developed in the project since it will permit to identify areas of improvement for each one. On the other hand, it will permit to study how better performance can be obtained by combinations of various approaches (i.e. physical and statistical). Under this perspective, ANEMOS shell will permit also the implementation and on-line operation of combined models. An objective estimation of the forecasting accuracy by the above benchmarking procedure is a major requirement by the end-users in order to be able to evaluate the risks of large-wind energy penetration.

A milestone of the project concerns the development of appropriate models for offshore wind farms, for which, no specific models exist today. Specificity is related to the large concentration of power and how the wind farm behaves in critical situations like the passage of fronts. It is also related to the variable roughness of the sea surface and the effects of marine meteorology, the coastal effects etc. In the frame of the project, the software will be installed to an offshore wind farm by one of the participating utilities for on-line operation.

Apart from the offshore installation, the ANEMOS tool will be installed for on-line operation to a number of onshore wind farms covering different cases like single wind farms, complex terrain, isolated or interconnected systems, and finally for upscaling purposes, that is for the prediction of wind resource at a regional or national level. This range of applications will permit to evaluate in detail the performance of the models developed within the project under various operating conditions. The benefits from wind prediction will be analysed under different angles with emphasis to the contribution of forecasting techniques to wind power integration in a liberalised market environment.

2. Description of the consortium

The research to be carried out for the ANEMOS project requires the close co-operation of researchers having experience in the different fields of wind energy and meteorology. The partners of the consortium (research institutions, energy companies, power utilities, meteorological services, TSOs) present a high complementarity, since they have already been involved in research on different fields related to renewable energies. Moreover, the partners have a long record of successful co-operation in previous EU projects and have already worked together in past research projects. Each partner has acquired in-depth expertise in one or more of the fields concerned in the ANEMOS project. Each participant is also the key partner in its country:

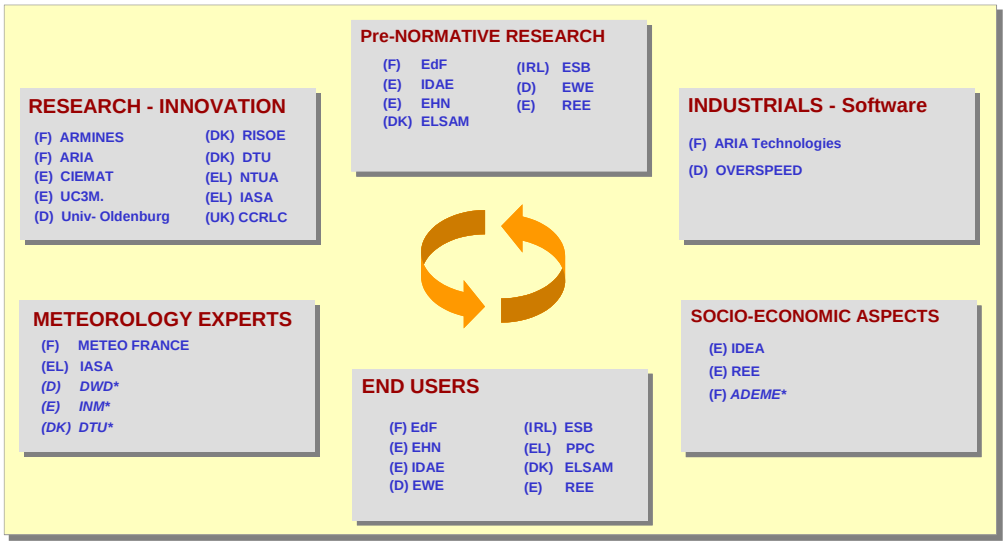

Figure 1: *Competences covered by the ANEMOS consortium (* denotes expertise through subcontracting or partners following closely the project).*

ARMINES-ENSMP/CENERG : The ***CENERG (Centre d'Energétique)*** is a Joint Research Unit– Common Laboratory composed by two entities ARMINES and ENSMP ("Ecole Nationale Supérieure des Mines de Paris"), which are involved in the current development of this Research Centre (personnel, employment, overheads, investment, etc).

ENSMP "Ecole Nationale Supérieure des Mines de Paris" is one of the so-called French "grandes écoles". Originally charged with the training of civil mining engineers and the Corps of Mines, since the Sixties the School has developed its post-graduate research and teaching activities in engineering sciences and related social sciences in liaison with industry and with the help of the **ARMINES** association ("Association pour la Recherche et le Développement des Méthodes et Processus Industriel").

Created in 1967 through the efforts of ENSMP, ARMINES is a contract-based research association. Funded under an agreement with the French government and operating under the control of an auditor and a government commissioner, ARMINES has extended its activities to encompass similar to ENSMP Schools, under the supervision of the Ministry of Economy, Finance and Industry.

ARMINES is providing a convenient frame for contractual relations between industry and academic laboratories. The latter are linked to ARMINES through the creation of "Joint Research Units – Common Laboratories". ARMINES and ENSMP are linked through a mandate of management giving to ARMINES the administrative, financial and legal responsibility to follow in particular the European contracts obtained by their Joint Research Unit – Common Laboratories. The ***CENERG (Centre d'Energétique)*** is one of these Joint Research Unit – Common Laboratories.

ARMINES-ENSMP/CENERG is the general co-ordinator of the project and will also co-ordinate the WP-6 on the development of the ANEMOS prediction platform. It will develop prediction and downscaling models based on Artificial Intelligence and high-resolution meteorological information. It will investigate the use satellite-radar information for the offshore. ARMINES has developed on-line prediction modules for the EU More-Care project.

OVERSPEED will lead WP-1 on data collection and evaluation of needs. It is an industrial company specialised on wind energy applications and monitoring of wind farms. This enables OVERSPEED the most appropriate partner to handle data collection task, which is critical for the success of the project. OVERSPEED has professional experience on communication interfaces for on-line software operation and experience on web-based interfaces. For this, it has been selected to undertake the development of the communication interfaces of ANEMOS in collaboration with ARIA who will focus on the development of other parts of the software (MMI, database, etc).

CIEMAT (Centro de Investigaciones Energeticas, Medioambientales y Technologias) will coordinate the WP-2 on the off-line evaluation of the models developed in the project and their comparison to existing models. CIEMAT has experience on physical and statistical modelling. CIEMAT will provide meteorological forecasts for the cases of Spain obtained through its standard collaboration with the meteorological service of Spain.

DTU (The Danish Technical University - Informatics and Mathematical Modelling) will lead WP-3 and will develop statistical models for tasks of ANEMOS with emphasis on model calibration and initialisation based on physical knowledge, on-line measures for the expected error and wind farm power curve modelling. DTU disposes considerable experience from the development of the WPPT prediction model and its contribution to the Zephyr prediction system.

RISOE (Risø National Laboratory) will coordinate the WP-4 on physical modelling. It will develop models for complex terrain and advanced model output statistics based on high-resolution meteo information. RISOE has developed Zephyr and Prediktor prediction tools and this experience will be valuable for the specifications and the development of ANEMOS. RISOE will consist an interface to EU project ENDOW which studies offshore resource.

Univ-Oldenburg (Department of Semiconductor & Energy Research, University of Oldenburg University of Oldenburg) will lead the WP-5 on the development of prediction models for offshore wind farms. Univ-Oldenburg has developed the Previento model and has experience on offshore modelling and on upscaling (prediction of regional wind power). It will work with both statistical model and mass-consistent physical models for downscaling. It will also provide meteo forecasts for the case-studies in Germany following its collaboration with the German Meteo Service DWD.

UC3M (Carlos III University of Madrid) will lead the WP-8 on the evaluation of the on-line operation of ANEMOS for the onshore and offshore installations. It will work on advanced statistical models for short and very short term and automated processes for model tuning. UC3M has experience from developing the Sipreolico prediction model.

CCLRC/RAL (The Energy Research Unit of Rutherford Appleton Laboratory) has experience on statistical modelling for wind prediction from the development of on-line modules for the More-Care project. RAL will consist an interface to EU project POWER to study effect of wind prediction on liberalised market and offshore meteorology.

ARIA Technologies is an industrial partner who has developed commercial software for wind energy applications (i.e. resource assessment). It will study the contribution of cfd modelling to downscaling of wind power in complex terrain. ARIA will develop the ANEMOS software in collaboration with OVERSPEED applying industrial standards.

IASA (Institute of Accelerating Systems and Applications - University of Athens) has developed the SKIRON NWP system (15x15 km), which is used by the Greek Meteorological Service. IASA has developed and operates the advanced RAMS model (1-2 km) that will be used to the 2004 Athens Olympics. In the project it will provide weather forecasts for Crete and other case-studies of ANEMOS by both SKIRON and RAMS, and will develop Kalman filter based prediction models.

METEO-FRANCE is the national meteorological service of France and has already participated in resource assessment projects. Its participation in ANEMOS will permit to anticipate ongoing wind energy development in France. METEO-FRANCE will provide high-resolution meteorological forecasts (1-2 km) for the sites where ANEMOS will be installed for on-line operation in France. It will be an assistant partner to ARMINES.

EDF (Electricité de France) will install and operate ANEMOS to a number of wind farms in Mainland in France and in Corsica. It will participate to the data collection and, as an end-user, to the specifications of the software. EDF will contribute to the pre-normative research on the form of data and prediction software. EDF

will use its Energy Management Software for operational planning to evaluate the benefits from wind prediction. The operation of ANEMOS by EDF will contribute to the efforts of the utility to develop wind energy in France in the coming years. EDF will be an assistant partner to ARMINES-CENERG.

EHN (Energia Hidroeléctrica de Navarra, S.A) has installed 1000 MW of wind power in Spain. It will install ANEMOS to operate on-line for a number of wind farms. The case of EHN is a representative one for relatively complex terrain and large-scale integration. EHN will provide data, contribute to the specifications and to pre-normative work as an end-user of wind prediction tools. EHN will be an assistant partner to CIEMAT.

ELSAM is a Danish Utility recognised as a pioneer on wind energy development. It will provide data for onshore and offshore wind farms. ANEMOS will be installed for on-line operation at ELSAM and more precisely for the prediction of a number of onshore (flat terrain, near-shore) and *offshore* wind farms. The application to an existing large offshore wind farm is a major contribution to the project and will consist a pilot case for the management of offshore installations. ELSAM will be an assistant partner to DTU.

EWE is a German Utility with 1500 MW installed wind power. EWE will provide data and will install and operate ANEMOS for a number of wind farms. The application of ANEMOS will permit to evaluate in detail upscaling methods for estimating wind power in a large scale. EWE will be an assistant partner to the University of Oldenburg.

ESB is an Irish Utility with 124 MW installed wind power. This figure is projected to increase to over 600 MW by 2005. ESB recognises the necessity of an accurate prediction tool to help manage wind power and facilitate the integration of such large amounts of wind power in Ireland. It will participate in data collection and subcontract NWP forecasts by the HIRLAM system to be used in the project. It will contribute to the specifications and to pre-normative work as an end-user of wind prediction tools. It will install and evaluate the ANEMOS software for predicting the output for a number of windfarms in Ireland. A synergy will be established between the tools of More-Care project for Ireland and ANEMOS. ESB will be an assistant partner to ARMINES-CENERG.

PPC (Public Power Corporation-Transmission Department of Crete) will provide data to the project and will install ANEMOS for on-line operation. The system of Crete is a large autonomous system with high wind penetration (67 MW installed wind power for a load between 180-450 MW). Crete combines complex terrain, weak grid and climate that is highly affected by marine meteorology. PPC gives a priority to the integration of wind prediction in the management of the power system. An interface will be developed so that the advanced predictions from ANEMOS can be used by the More-Care Energy Management System operating in Crete. PPC will be an assistant contractor of ARMINES-CENERG.

IDAE has been involved in the development of 24 wind farms in Spain (total 280 MW). IDAE will contribute to the definition of end-user needs, to the analysis of the market development for wind prediction and dissemination of the results of the project. IDAE will test the forecasting system on a pilot wind farm in Spain with different wind turbine types. This will permit to validate power curves models. IDAE will be an assistant contractor of CIEMAT.

REE is a Transmission System Operator (TSO) of Spain. REE will contribute to the definition of the end-user requirements from the TSO point of view and by contacts to different wind farm developers. REE will enhance the pre-normative research in the project so that ANEMOS becomes a transferable technology applicable in a large scale and thus facilitating wind integration. REE will be an assistant contractor of CIEMAT.

ICCS/NTUA (Institute of Communication and Computer systems of the National Technical University of Athens) will develop models on statistical prediction using neural networks. It will use advanced power system management software to evaluate the benefits from wind prediction and the effect of different levels of prediction accuracy. ICCS/NTUA will be assistant partner to ARMINES-CENERG.

Figure 2: *EU member States involved in the project.*