Project funded by the European Commission under the 5th (EC) RTD
Framework Programme (1998 - 2002) within the thematic programme
"Energy, Environment and Sustainable Development"

Project: DISPOWER

Contract No. ENK5-CT-2001-00522

D 5.3 "ADAPTATION AND EXEMPLARY IMPLEMENTATION OF DG-SPECIFIC PREDICTION SYSTEMS"

Document Type: Deliverable

Author:	Bernhard Ernst
Company:	ISET e.V.
Address:	Königstor 59, 34119 Kassel, Germany
Tel.:	+49 561 7294 372
Fax:	+49 561 7294 200
Email:	bernhard.ernst@iset.uni-kassel.de
Further Authors:	George Kariniotakis, Niels Siebert, ARMINES; Julien Ottavi, EDF; Lucy Aitchison, IT Power; Kurt Rohrig, ISET
Reviewer:	Rita Shaw, IT Power;
Approver:	Cornel Ensslin, ISET

Document Information:

Document Name: del_2004_0030
Rev.Date: 2004-06-07
Classification: R5: T 5.3
Status: S0: approved

Abstract:

The internet-based information system for energy management, which is being developed in WP5, will facilitate information exchange between actors in the RES+DG generation and trading sector, where forecasting of intermittent generation is crucial. Since wind power is the major contributor of intermittency in power systems, its predictability is of particular importance and which a number of models and tools are devoted to. It is Deliverable 5.3 that for the first time two most important wind power prediction tools are adapted and proved in a practical application in the UK.

Executive Summary

Work package 5 of the DISPOWER project is under way to elaborate and develop a new internet-based information system for energy management in decentralised generation systems. Such a system enables an exchange of information and data between the actors in the RES+DG generation and trading sector. A major part of such an information system is a forecast system for RES + DG generation, as has been developed and tested within Task 5.3 with respect to wind energy. For the first time the most important wind power prediction tools could be compared and proved in a practical application in the UK.

The requirements of a forecast tool differ remarkably as can be seen from the specifications set by Electricité de France (EDF) and the British New Electricity Trading Arrangement (NETA). While EDF needs a most accurate forecast 48 hours ahead, the NETA plans with an one-hour ahead prediction.

In subtask 5.3a) EDF has described its requirements in detail. Currently, because of the low level of wind power in France, no urgent need for wind power forecasting is yet felt. However, this need will be felt as soon as the installed wind power reaches a few per cent of total French production capacity which is of the order of 120 GW. In brief, EDF’s requirements on a wind power forecasting system are:

EDF as a producer subject to the obligation to purchase

The use of a relatively short term wind power production forecast can intervene in two production management processes which are the responsibility of the producer EDF: daily forecasting management and weekly planning.

Daily planning

EDF COOP is in charge of drawing up the production plan the day before for the following day, for EDF in mainland France. Because of the obligation to purchase, wind power production is considered as an inevitable production included in EDF's supply. To be able to proceed on day *D*-1 with the forecasting management of planning for day *D* of all the available production assets, the wind power production must be known with a time step of 30 minutes.

Weekly planning

The weekly planning carried out by EDF COOP in liaison with EDF Trading is aimed at negotiating the short-term bilateral contracts, planning the guaranteed stops for certain production units, constructing the scale of demand on the production units and triggering charging decisions (tariff incentives aimed at reducing the consumption curve at the peak time: for example, setting up cheaper tariffs during off-peak hours). Here too a forecast of wind power production is essential.

EDF as energy trader on the French and European markets

The use of a wind power production forecast by an energy trader is not exactly identical to that of the producer in charge of production planning. In fact, the forecast of production (and of demand as well) is only a tool for helping with decision-making which will determine where the traders stand. Hence a more "statistical" approach of the forecast and associated uncertainties is used. Nevertheless, the requirements for the forecast the previous day for the next day remain fairly similar to those expressed by the producer.

Necessary Accuracy of the forecast

The main quality of a wind production forecasting tool lies in its ability to anticipate the level and the fluctuations in wind power production to come with at least 48 hours' notice with good accuracy. In fact, the quality of production planning carried out on the basis of a wind power production forecast depends totally on the quality of this forecast.

Conclusion of the requirements

The forecasting of wind power production will become a major stake for EDF as soon as the proportion of wind energy represents a few per cent of power produced. Although slightly different, the specifications of the requirements of the different operational units of EDF interested in such forecasting can be fulfilled by a single forecasting tool, provided that the output interface can be modular and allows the output format to be adapted. The accuracy of the forecast and the quantification of uncertainties are the key points of such a tool.

The increase in the rate of penetration of wind energy could eventually lead EDF in the first place to modify the specifications of the forecasting tool presented here and perhaps, later, its methods of production management in order to improve the integration of wind power to exploit this energy to the best advantage. In these conditions, other specifications could then come to light which will probably involve a more frequent update of the forecasts, the drafting of an overall forecast to work out the forecast uncertainty better, a forecast not only in quantitative terms (that is, a production forecast) but also in terms of phenomena (forecast of qualitative variables: production/no production, risks of large fluctuations, …), and other more precise specifications.

Comparison of forecasting systems

In a further subtask of Task 5.3 several wind power forecast tools that are under development or already in operation has been analysed in terms of their working principles in order to fulfil EDF’s requirements. Currently there are two main state-of-the-art approaches; one based on physical or deterministic modelling and a second one based on statistical or time-series modelling.

The “physical” approach for wind power forecasting is based on a detailed description of the wind farm site (orography, roughness, obstacles), the wind turbines (hub height, power curve, thrust curve) and the layout of the wind plant. The main inputs are numerical weather predictions (NWP). The alternative “time-series”, or statistical, approach includes typical linear models (ARMA, ARX etc) and non-linear ones (i.e. fuzzy-neural network models, artificial neural networks, conditional parametric models, etc).

These models aim to predict the future by “capturing” temporal and spatial dependencies in the data. The input to these models can be on-line supervisory control and data acquisition (SCADA) data and NWP. For look-ahead times more than ~10 hours, NWPs are indispensable for an acceptable performance since they represent weather dynamics that cannot be modelled using only recent on-line data. On these look-ahead times both physical and statistical approaches have similar performance. For shorter horizons, up to ~1-8 hours ahead, time series models can be based on recent measurements in addition. Hence, they are able to provide are high accuracy even if there are errors in the NWP.

Within Task 5.3 two of these systems, ISET’s Advanced Wind Power Prediction Tool (AWPT) and Armines Wind Power Prediction System (AWPPS), have been successfully adapted and tested on six wind farms in the UK, providing a two hour forecast based on online measurements and numerical weather forecast from the UK Met Office.

The cores of the models are based on artificial neural networks (ISET) and adaptive fuzzy neural networks (Armines). They are integrated in the Wind Power Management System and in the More-Care Energy Management System respectively. Here, they have been used as a stand-alone system and adapted for the UK case.

Globally, the results reached in this task of the DISPOWER project are very satisfactory for the problem of single wind farm forecasting and comparable to the ones found in the literature. For instance, it can be seen that the RMSE is lower than 12.9% of the installed capacity for all the case studies. Moreover, the improvement w.r.t. persistence raises up to 21.9% for the RMSE criterion and to 18.5% for the MAE criterion depending on the case study. Regarding the error distributions, one can notice that they are quite sharp and the number of outliers is negligible. These results can be considered as base-line ones. For an on-line installation of the prediction systems, additional optimizations are performed for an optimal on-line performance.

Table of contents:

1 Introduction

The development of wind power has been a success story in Europe. A large level of installed capacity has already been achieved, and major growth is still predicted. When considering an installed capacity of over 29000 MW in Europe [www.ewea.org], the EWEA target of 60,000 MW by 2010 seems easily attainable. Wind-generated power now constitutes a noticeable percentage of the total electrical power consumed, and also exceeds the base load on the network in some utility areas. This indicates that wind is becoming a major factor in electricity supply, and in balancing consumer demand with power production.

A major barrier to the integration of wind power into the grid is its variability. Because of its dependence on the weather, the output cannot be guaranteed at a particular time. This makes planning the overall balance of the grid difficult, and biases utilities against using wind power. Accurate forecasting of power inputs from wind farms into the grid could improve the perception of wind power, and help utilities both to accept and promote it.

Within the DISPOWER work package 5 "INFORMATION, COMMUNICATION AND ELECTRICITY TRADING", wind power prediction plays a major role as service tool to be integrated into an information system for RES-E (Electricity produced from Renewable Energy Sources). Such a system will improve the integration of RES-E and will lead to new assessment and a higher capacity level.

The requirements regarding wind power prediction systems vary considerably depending on the specific market and the distribution of wind turbines. Therefore, in task 5.3a) first an analysis was made of the requirements of a forecasting system. As an example the French utility Electricité de France (EDF) has defined its requirements for a wind power forecasting system in detail (see chapter 2). EDF for instance, wants a day-ahead as well as a week-ahead forecast. The value to be forecasted is the mean wind power production over thirty minutes, on a national scale (France and other European countries) and on a regional scale. The British New Electricity Trading Arrangement (NETA) includes completely different requirements. The spot market closes only one hour before the time of delivery. In Denmark and Germany, predictions are mainly used for the day-ahead market, which closes at noon in Denmark (i.e. up to 36 hours before time of delivery) and at 3 p.m. in Germany (up to 33 hours before the time in question). Hence, the requirements for wind power forecast systems are usually set by market operation constraints, not by technical or physical constraints. The hydro-based system in Scandinavia, for instance, does technically not require a 36 hour forecast as the hydro system can adjust generation in a fraction of an hour. However, market operation requires a 36 hour forecast. In addition to the different time spans that forecasts cover, different spatial resolutions are required. In Denmark and in Germany, for instance, wind turbines (WTs) are spread all over the country. Therefore, the wind power is mainly forecasted for large areas. In the US and in Spain, the installed wind power is limited to a number of large wind farms. This requires a forecast for single wind farms instead of wide areas. In Task 5.3a) several existing forecasting systems have been compared to see what requirements they can meet (see chapter 3 for details).

As a special case study Task 5.3 is looking at predicting outputs from six single wind farms in the UK. Two optional models for doing this are being examined – the ISET artificial neural network model and the Armines fuzzy neural network model. The input data for the two models is being provided for six UK wind farms through IT Power. Weather data comes from the Met Office (the UK's national meteorological office and a partner in the DISPOWER project) and wind farm data comes from National Wind Power (a major wind farm operator and part of RWE). National Wind Power is represented in the DISPOWER project by IT Power.

ISET and Armines have completed simulations using data from the period January 2001 to July 2002. The ISET predictions are now examined by IT Power to look at the commercial value of the predictions under NETA. The results from the Armines model will also be used by IT Power to look at the commercial value.

Further data is being provided by both the Met Office and National Wind Power for 2004 to allow ongoing testing of the models, and further refinement to the needs of NETA. This is necessary as a full year of data is required to train the neural networks, and further data is then required to test the accuracy of the simulations.

National Wind Power already have a 'modified persistence' model which they use for predictions. The intention is to investigate how this compares in accuracy with the models produced under the DISPOWER project.

1.1 The Need for Prediction Models for the Open Market

Wind power's variability can also affect the price that is paid for wind electricity. Some countries give a subsidised price, higher than the pool price, to wind generators. The trend, however, is towards deregulated electricity markets. Under these regimes, producers may have to contract to provide a firm quantity of power and might be penalised if they overproduce or underproduce. This reduces the value of the energy they sell, which, in turn, reduces the incentive to invest in wind energy. By aggregating the power output of wind farms and obtaining accurate predictions of the power that will be fed into the grid, the achieved price might be higher. And this would make wind power a more favourable investment. Higher prices would also means that more sites become feasible, as those with lower average wind speeds would become economic.

It is evident that in the future those players of the deregulated electricity market who rely on RES-E for a considerable part of their production will initiate a speedy development of better prediction models. There will be considerable economic incentives for this development since the incorrectly reported part of the wind power production must be balanced over the real-time market against considerable extra costs determined by the aggregate need for regulating power and the market demands as such. According to the calculations in the accuracy of the prognostic tools should be improved to more than 90% to reduce the costs for regulating power to an acceptable level. Due to the fact that meteorological forecasts - in spite of the improvement in technology and models – still are encumbered with a certain degree of uncertainty this might be a difficult task.

Since the development, optimisation and application (know-how) of these prediction systems will be an important parameter in the competition, the market players look into these issues on an individual basis. The purpose of forecast systems will be to reduce these market risks and will hence only indirectly allow for the requirements of the system.

1.2 The Need for Prediction Models for the Network Operators

Improved prediction models will also be required by the Transmission System Operators (TSOs) who will be responsible for the operation of the electrical system on a deregulated market, including perfect balance between production/export and demand/import at all times. At a short notice - a matter of minutes - the TSO must be able to take measures to compensate for all deviations, where a forecast cannot be made, between actual and scheduled cross- border exchange, for example due to unexpected fluctuations of the production.

The TSO must purchase regulating power direct from the market players or on a special real-time market. This means that it will no longer be relevant to talk about excess electricity or "power value" for wind turbines since any excess or deficient turbine production will be balanced via the real-time market.

Most likely a considerable wind power expansion will lead to a higher degree of co-ordination between the TSOs of a country in terms of expansion and exploitation of the regulating reserves. It will have to be examined whether the present agreements and rules within NORDEL and UCPTE, respectively, will need revision in this respect, both as a result of the deregulation of the electricity market and as a result of the expansion with fluctuating RES-E. Especially the rule for Area Control Error (ACE) could lead to considerable investments in regulating power plants in areas with high penetration of stochastic RES-E.

2 Requirements for a forecasting tool for wind power production in France

2.1 Wind power in France

The European directive on renewable energy anticipates increasing the proportion of electricity from renewable sources from 15% of French consumption to 21% in 2010. Such an increase implies the production of 46 TWh per annum from new sources of production. Only part of this energy is wind power; however, the different scenarios studied by the Ministry of Industry, the Economy and Finance allow for production of this type between 10 and 25 TWh in 2010.

At present, with 147 MW of wind power installed in Metropolitan France and the overseas départements and territories, France is in eleventh place with respect to the rest of Europe. It has therefore accumulated a significant delay with respect to the other countries in the European Union, while its potential of 156 TWh/year is the second in Europe. Wind power in fact only covers 0.02% of France's electricity consumption.

However, the legislative and institutional context in France has evolved, allowing us to envisage strong development of this type of energy in the next 10 years. ADEME (Agence pour le Développement et la Maîtrise de l'énergie [Agency for the Development and Control of Energy] - a government agency) is relying on 10,000 MW by 2010, and the Ministry of Industry, the Economy and Finance expects an installed power of between 4,000 and 9,000 MW by the same time.

Because of its minimal development, wind power in France does not currently pose any difficulties of integration into the mainland electrical system. However, EDF, as the major player on the French electrical scene, is now anticipating the consequences on the processes of production management and on the real-time management of the electricity system of a significant input of wind power.

2.2 The relevance of forecasting wind power production for EDF

2.2.1 The organisation of the French electricity system: an evolving situation

EDF, as a public company, originally had the monopoly on the production, distribution and transport of electricity in France. It was therefore responsible for trading electricity in Europe, real-time management of the balance of supply and demand, the management of all the networks (transport and distribution) and the forecasting management of all production in France (including that of producers such as SNET and CNR, contractually linked to EDF, which have since become independent producers) on a daily as well as weekly and annual scale. The totally integrated management of production was achieved in order to minimise costs.

2.2.2 The opening of the French market to competition

The opening up of the French electricity market should in the medium term allow the application of the European directive of 19 December 1996 concerning the European electricity market. This opening has been implemented progressively.

The Commission de Régulation de l'Electricité (CRE) [Commission for Regulation of Electricity] was formed in March 2000. The major tasks of the CRE cover the guarantee of access to the network and control of market regulation.

The RTE (Réseau de Transport d'Electricité [Electricity Transport Network]) has been made independent of EDF and plays the part of an ISO (Independent System Operator). It is responsible for managing the transport network (voltage levels 63 kV, 90 kV, 220 kV and 400 kV) and owns them.

The situation on the French market is currently still that of a largely bilateral system. Only customers whose annual consumption exceeds a certain threshold (so-called eligible customers, with the eligibility threshold currently at 9 GWh) can choose their producer. Eligible customers and producers determine by contract the electricity supply conditions (price and quantity). The CRE declared itself in favour of the creation of a spot market. The French electricity exchange Powernext has actually been operational since November 2001.

2.2.3 The roles of EDF in the French electricity system

EDF henceforth has a dual role in the French electricity system: that of producer-trader linking the wholesale trade in electricity with production (with an energy mix comprising conventional thermal, hydroelectric, nuclear and renewable resources) and that of manager of the distribution network. But EDF's distinctiveness does not stop there. Because of its past position in France, EDF has been subjected to a certain number of constraints linked with renewable energy: the obligation to buy this energy at rates fixed by decree, the connection to the distribution network of renewable energy production power stations and the integration of these energies into its balancing perimeter.

The obligation to purchase imposed on EDF

The law of 10 February 2000 requires that EDF is obliged to conclude a contract of purchase of the electricity produced by installations of which the installed power per production site does not exceed 12 MW which produce renewable energy. The purchase prices of electricity of wind origin were fixed by the decree of 8 June 2001 which appeared in the JO [Official Journal of the European Commission] on 22 June 2001, and those for electricity produced by the radiative energy of the sun were fixed by the decree of 13 March 2002 which appeared in the JO on 14 March 2002.

For wind power, the purchasing prices are as follows:

Tariffs in euro cents (c€)	Installations covered in Annex 1 of the decree of application of the law of 10 February 2000 (wind power installations < 12MW)	
	1 to 5 years	6 to 15 years
Continental France	8.38	8.38 to 3.05 (1)
Outside continental France	9.15	9.15 to 4.57 (2)

		(1) According to availability and threshold of 1500 MW (2) According to availability

The tariff is fixed for the first 5 years of operation of the wind farm then decreases for the next 10 years as a function of the total installed wind power resources in France (continental France) and as a function of the particular availability of the site (calculated as number of hours equivalent to operation at nominal power). These tariffs have caused a craze for investors, with the annual rate of return of an installation estimated at 15%, hence the expected development of installed wind power resources in France.

In view of the wind-generated power expected in France, the amount of the purchasing obligation will represent a significant burden for EDF. At first, this obligation will be financed by a fund called the Fond Commun du Service Public [Common Public Service Fund], fed by all the producers operating on the French electricity market (including EDF of course). This fund will remunerate EDF for assuming the obligation to purchase not on the basis of the purchase obligation tariff but by deducting the avoided costs which appear through the use of wind resources rather than conventional production means. Actually, if the wind power production thus purchased is not enhanced as much as possible, EDF could lose financial resources because of this obligation to purchase.

Integration with the distribution network

In addition, these production installations are connected to the 20 kV high voltage network or even to the low voltage network which are both integrated into the distribution network and are therefore managed by EDF, outside RTE which manages the higher voltage levels (63 kV, 90 kV, 220 kV and 400 kV).

The connection of this production to a distribution network intended to serve consumer customers at minimum cost poses a certain number of technical problems connected with the tree structure of this type of network (no permanent loop), with the management of the voltage plan which has the purpose of controlling active and reactive voltage drops which increase from upstream to downstream and with the protection plan which starts from the principle that user applications are passive and do not generate short-circuit current.

Integration into the balance perimeter

Because of the obligation to purchase, the renewable energy resources are integrated into the supply of EDF as producer. As wind power is a particularly fluctuating energy source, if it is not correctly forecast, its introduction into EDF's production will increase the deviations between supply and demand in real time obliging RTE (responsible for the adjustment between supply and demand in real time) to resort more frequently to the system services (reserves) or to adjustment supplies (recourse to the spot market).

During the procedure for adjusting deviations between production offered and production actually produced, the financial burdens which EDF will have to bear risk undergoing a significant increase.

In addition, taking into account the fact that the wind is intermittent and the inevitable nature (not storable) of the wind flow, the wind power production units cannot participate in the system services. In the context of load monitoring, this can increase the manoeuvrability requirements of the other resources of the producer EDF or increase the requirements for reserve resources.

2.2.4 Special cases of Corsica and the DOM/TOM

The Corsican electricity network and the networks of the overseas departments and territories (DOM, that is, La Réunion, the French West Indies, Saint Pierre et Miquelon and French Guiana, TOM, that is, French Polynesia, New Caledonia,…) are completely managed by EDF which therefore also plays the part of ISO. These island networks are not interconnected and are therefore more sensitive to the integration of wind power. Corsica currently has an installed power of 12 MW and Guadeloupe (including Désirade and Marie-Galante) has 10 MW. These power levels already need to have the production management processes adapted.

On these networks, EDF plays the part of producer responsible for the forecasting management of the supply-demand balance, the part of manager of the electricity system responsible for the adjustment between supply and demand in real time and the part of manager of the electricity distribution network. These requirements for forecasting tools for wind power production are therefore much more extensive on these island networks.

Note that these networks present a real "experimental" interest because of the scale factor existing between these networks and the mainland French network. Actually, a low level of installed wind power in Corsica corresponds to quite a high rate of penetration which enables us to get an idea of the difficulties which will arise when there is a massive input of wind power production in France.

2.3 EDF's requirements

We can therefore see that the integration of wind power production presents a number of important stakes for EDF. Including a forecast of production of this type would enable us on the one hand to ease the excess costs considered as inevitable, and on the other hand to make the most of a type of energy which is for the moment essentially endured as a disruption, not to mention that the development of a market in green certificates would further enhance its value (and therefore the value of accuracy).

Because of the multiple roles of EDF in the French electricity system, EDF's requirements for forecasting tools for wind power production are also multiple. It is proposed to identify the requirements corresponding to each of EDF's roles. We have excluded from our considerations the specific needs of RTE responsible for the adjustment between production and consumption in real time.

The requirements expressed here are based on interviews held with EDF-Trading, a subsidiary of EDF responsible for electricity trading on the European markets and with operational units of EDF in charge of production management on a daily basis and on a weekly basis (EDF COOP).

The results are presented in the form of a list of specifications in terms of functionalities, inputs and outputs of the forecasting tool. Some of these specifications cover purely IT aspects. In general it should be realised that these tools will be used operationally, which means that they must show a very high level of reliability, robustness and security, on both the hardware and software sides.

Finally, a special chapter deals with the accuracy expected by the users of such a tool.

2.3.1 EDF as a producer subject to the obligation to purchase

The use of a relatively short term wind power production forecast can intervene in two production management processes which are the responsibility of the producer EDF: daily forecasting management and weekly planning. For the moment, because of the low level of wind power in France, the need for wind power forecasting is not felt. However, this need will be felt as soon as the installed wind power reaches a few per cent of total French production capacity which is of the order of 120 GW.

Daily planning

EDF COOP is in charge of drawing up the production plan the day before for the following day, for EDF in mainland France. Because of the obligation to purchase, wind power production is considered as an inevitable production included in EDF's supply. To be able to proceed on day *D*-1 with the forecasting management of planning for day *D* of all the available production assets, the requirements of EDF COOP are as follows:

- The amount to be forecast is the mean wind power production over thirty minutes on a national scale (France)
- The forecast must be received on day *D*-1, before 06:00 UTC
- The forecast has a timescale of 48 hours (in fact until day *D*+1 at 00:00 UTC)
- The time step for the forecast is 30 minutes (i.e. 48 points per day)
- The uncertainties of the forecast must be expressed for each half-hour step in the form of a high value and a low value (upper and lower limits of a confidence interval) framing the mean value
- The forecast is updated daily (before 06:00 UTC on day *D*-1 for day *D*, before 06:00 on day *D* for day *D*+1, and so on)
- The tool's interface must present a comparison between production forecast and achieved (therefore an ability to archive past forecasts, past achievement and the forecast in progress)
- The output format of the forecasting tool must be easy to modify (to ensure compatibility with EDF's internal tools): an output in the form of an ASCII format file seems to be a satisfactory solution.

Note that because of the obligation to purchase, EDF has information on the production achieved on the wind power sites in France (possibility of using this data for statistical modelling); on the other hand, the data on the local meteorology of the wind power production sites (such as wind measurements on the meteorological masts of the wind farms) is apparently not available.

EDF must also make available to the network management a margin of production available in real time, a margin of which the dimensions (that is, the value of power required) are calculated each day by RTE. In order to evaluate the level of demand on the reserve thus set up, EDF COOP must have an indicator representative of the fluctuations in wind power throughout the day (fluctuations connected with particular turbulence conditions, for example, the presence over France of a trailing sky with gusts under cumulonimbus).

An estimate of the standard deviation of the fluctuations in wind power on a countrywide scale, for a length of time and a time step identical to those of the production forecast, must be provided in parallel with the forecast described above.

An alert message must be generated if the meteorological situation risks causing a massive triggering of the wind power equipment following the disengagement threshold of the wind generators being generally exceeded. This message must specify the nature of the phenomenon and its predicted date of occurrence.

Weekly planning
The weekly planning carried out by EDF COOP in liaison with EDF Trading is aimed at negotiating the short-term bilateral contracts, planning the guaranteed stops for certain production units, constructing the scale of demand on the production units and triggering charging decisions (tariff incentives aimed at reducing the consumption curve at the peak time: for example, setting up cheaper tariffs during off-peak hours).

Here too a forecast of wind power production is essential. The requirements in this area are similar to those expressed for daily management:

- The forecast is a forecast of mean production over thirty minutes on a national scale (France), with a timescale of at least 5 days (ideally 10 days).
- The forecast is updated daily always for a sliding timescale of 5 to 10 days.

2.3.2 EDF as energy trader on the French and European markets

The use of a wind power production forecast by an energy trader is not exactly identical to that of the producer in charge of production planning. In fact, the forecast of production (and of demand as well) is only a tool for helping with decision-making which will determine where the traders stand. Hence a more "statistical" approach of the forecast and associated uncertainties is used. Nevertheless, the requirements for the forecast the previous day for the next day remain fairly similar to those expressed by the producer.

- The amount to be forecast is the mean wind power production over thirty minutes on a national scale (France and other European countries) and on a regional scale
- The forecast must be received on day *D*-1, before 06:00 UTC (before the European markets open)
- The forecast has a timescale of 48 hours (in fact until day *D*+1 at 00:00 UTC)
- The time step for the forecast is 30 minutes (that is 48 points per day)
- The uncertainties of the forecast must be expressed for each half-hour step in the form of a probability density of which the parameters are supplied (mean value, standard deviation, quantiles at 5%, 25%, 50%, 75%, 95%, for example)
- The forecast is updated daily (before 06:00 UTC on day *D*-1 for day *D*, before 06:00 UTC on day *D* for day *D*+1, and so on)
- A simplified re-updating of the forecast - that is with a time step of one hour - may be provided on day *D*-1 at 12:00 and 18:00 UTC in order to anticipate the deviations for day *D*.
- An estimate of the standard deviation of the fluctuations in wind power on the French scale, with a timescale and time step identical to those of the production forecast must be supplied in parallel with the forecast described above.
- An alert message must be generated if the meteorological situation risks causing a massive triggering of a significant part of a national wind generating grid anywhere in Western Europe following the disengagement threshold of the wind generators being generally exceeded. This message must specify the nature of the phenomenon and its predicted date of occurrence.
- If possible, for certain special cases of rapid variation in wind power production, the comparison of several forecasts is desirable (of great interest for example for general forecasts).

- The tool's interface must present a comparison between production forecast and achieved (therefore an ability to archive past forecasts, past achievement and the forecast in progress).
- The tool must also offer the ability to make calculations off-line using inputs from different sources, for example, by modifying the installed power, meteorological situation, availability of wind generators
- Output compatibility with at least one of the most commonly used software packages such as EXCEL, ACCESS, Oracle, SQL and SAS, is essential
- It is also desirable for such a tool to operate in a PC-type IT environment

In order to participate efficiently in weekly planning, EDF Trading also has a requirement in terms of longer term forecasting:

- The forecast is a forecast of mean production over thirty minutes on a national scale (France and other European countries), with a timescale of at least 5 days (ideally 10 days)
- The forecast is updated daily always for a sliding time horizon of 5 to 10 days.

The presentation of the forecast and of these uncertainties must be identical to that required for the forecast the previous day for the next day.

2.3.3 EDF as operator of the distribution network

In the island networks (in Corsica in particular), EDF also plays the role of operator (ISO) of the electricity system, responsible for load monitoring (adjustment in real time of supply and demand). In addition to the requirements already mentioned above, those specific to real-time management must be added:

- The most frequent possible update of the mean production forecast (at least every 6 hours)
- The most frequent possible update of the estimates of the standard deviation of the fluctuations in wind power on the scale of the network concerned, for a timescale and time step identical to those of the production forecast must be supplied in parallel with the forecast described above
- A more frequent update of the alert messages generated if the meteorological situation risks causing a massive triggering of a significant part of a national wind generating grid anywhere in Western Europe following the disengagement threshold of the wind generators being generally exceeded
- A calculation, re-updated as frequently as possible, of the performance of the forecast
- The interface of the tool must present a comparison between production forecast and achieved, updated as often as possible (therefore an ability to archive past forecasts, past achievement and the forecast in progress), a view of the availability of the wind generators as well as a presentation of the large scale meteorological forecast in progress
- The forecasting tool will be used within routing. The forecast must therefore be clear, intelligible and easy to obtain to allow decisions to be taken quickly and unambiguously

Of course, the spatial extent of the forecast is in this case that of the network concerned, for example, the whole of Corsica. Note that the requirements of RTE are apparently very similar if not identical.

2.3.4 Accuracy of the forecast

The main quality of a wind production forecasting tool lies in its ability to anticipate the level and the fluctuations in wind power production to come with at least 48 hours' notice with good accuracy. In fact, the quality of production planning carried out on the basis of a wind power production forecast depends totally on the quality of this forecast. If in addition the fluctuations in wind power production are in general greater during the day than the fluctuations in consumption, it appears that the forecast of the temporal evolution of wind power production has to be precise in time and in level of production: the quality criteria of such a forecast must in fact take these two aspects into account. In fact, a shift of half an hour in the forecast of a significant rise in wind power (due, for example, to a poor estimate of the speed of propagation of a depression), has a large excess cost, even if the amplitude of the rise is well forecast. Of course, a poor forecast of the level of production entails readjustments which are also costly.

It therefore appears essential to have as precise as possible a forecast, the value of this forecast (and therefore of the forecasting tool) being directly linked to its accuracy in time and level.

In the absence of experience of running the French electricity system with a high rate of penetration of wind power production, it is difficult for us at the moment to get an idea of what good accuracy actually is, that is of the level of accuracy from which the forecast is acceptable (and/or usable) and of the level of accuracy from which the gains contributed by an improvement in accuracy are less than the costs of the increase in accuracy.

Note on the one hand that to ensure correct management of the balance between supply and demand, RTE requires each producer to supply a production forecast on day *D*-1 for day *D* allowing a maximum error fixed at the minimum of the two numbers: 10% of the real load and 5 MW. On the other hand, the largest French unit on the electricity network has a power of 1450 MW (reactor of the nuclear power stations of stage N4). We can use these values as a basis for forging an idea of the accuracy from which a wind power production forecasting tool is useful: it must be capable of not being out by more than 1450 MW, that is, for a wind power capacity of 4000 MW installed power, this is equivalent to an absolute error in accuracy of the order of 36% (for a forecast for the whole of day *D* available on day *D*-1 at 06:00 UTC), therefore corresponding to the maximum inaccuracy acceptable from a forecasting tool. An error of less than 10% would be acceptable and such a forecast would be useful for the forecasting management of production. However, the use of production forecasting for electricity trading does not require such high accuracy: an uncertainty of the order of 10 to 20% (for a forecast valid for the whole of day *D* and available on day *D*-1 at 06:00 UTC) seems acceptable. However, in this context of use, special attention must be given to the accuracy of the forecast at peak times (around 08:00 UTC and in the evening, around 18:00 UTC in winter) and the slackest times of consumption (around 04:00 UTC).

The idea of good accuracy for a forecast longer than 48 hours remains particularly difficult to quantify. In this area and especially beyond 5 days, the requirements of users of forecasts can only be limited to hoping that they are as good as possible.

2.4 Conclusion

The forecasting of wind power production will become a major stake for EDF as soon as the proportion of wind energy represents a few per cent of power produced. Although slightly different, the specifications of the requirements of the different operational units of EDF interested in such forecasting can be fulfilled by a single forecasting tool, provided that the output interface can be modular and allows the output format to be adapted. The accuracy of the forecast and the quantification of uncertainties are the key points of such a tool.

We should note in passing the importance of a weekly production forecast which is not much used at the moment. This forecast would doubtless require the development of tools other than those anticipated to respond to the needs of forecasting on day D-1 for day D. Nevertheless, we have highlighted in the body of this report the specifications for such a tool to support this need which is of fairly significant economic importance. In fact, the negotiation of bilateral contracts between producers and customers is conducted on a weekly timescale, and important tariff decisions are also taken on this timescale which is not a very favourable timescale from the meteorological point of view. In our opinion, this path does nevertheless present an interesting margin of progression for increasing the economic exploitation of wind power.

The specifications described here represent only an initial view of what could be EDF's requirements in the field of production forecasting. For the moment, wind power production has no effect on the monitoring of consumption and on projected planning. It must be borne in mind that the requirements expressed here are completely dependent on the processes currently set up for the management of production - therefore with an electricity system where the largest hazard is consumption - and do not take account of the technical possibilities of the different methods of forecasting wind power production.

The increase in the rate of penetration of wind energy could eventually lead EDF in the first place to modify the specifications of the forecasting tool presented here and perhaps, later, its methods of production management in order to improve the integration of wind power to exploit this energy to the best advantage. In these conditions, other specifications could then come to light which will probably involve a more frequent update of the forecasts, the drafting of an overall forecast to work out the forecast uncertainty better, a forecast not only in quantitative terms (that is, a production forecast) but also in terms of phenomena (forecast of qualitative variables: production/no production, risks of large fluctuations, …), and other more precise specifications.

3 Overview of wind power forecasting tools

3.1 Overview

Wind power forecasting is a far from trivial problem. Wind speed is a non-stationary process both in the mean and variance. Wind power is non-linear w.r.t. speed with a major difficulty in the area of cut-off speed, where prediction intervals can extend from maximum to zero wind power. Among the difficulties, one should add the error of numerical weather forecasts, which are often used as input to the models. Often, no adequate information is available online by a data acquisition system (SCADA) to assess the actual operational status of the wind farm (i.e. how many turbines are in operation). The available on-line data can be detailed (i.e. power, speed of each wind turbine) or not (i.e. only total power available). In some situations there is complete lack of data and information from neighbouring wind farms has to be assessed.

Several research centres in Europe actively pursue research on wind power forecasting. Actually there are two main state-of-the-art approaches; one based on physical or deterministic modelling and a second one based on statistical or time-series modelling – Figure 3.1.

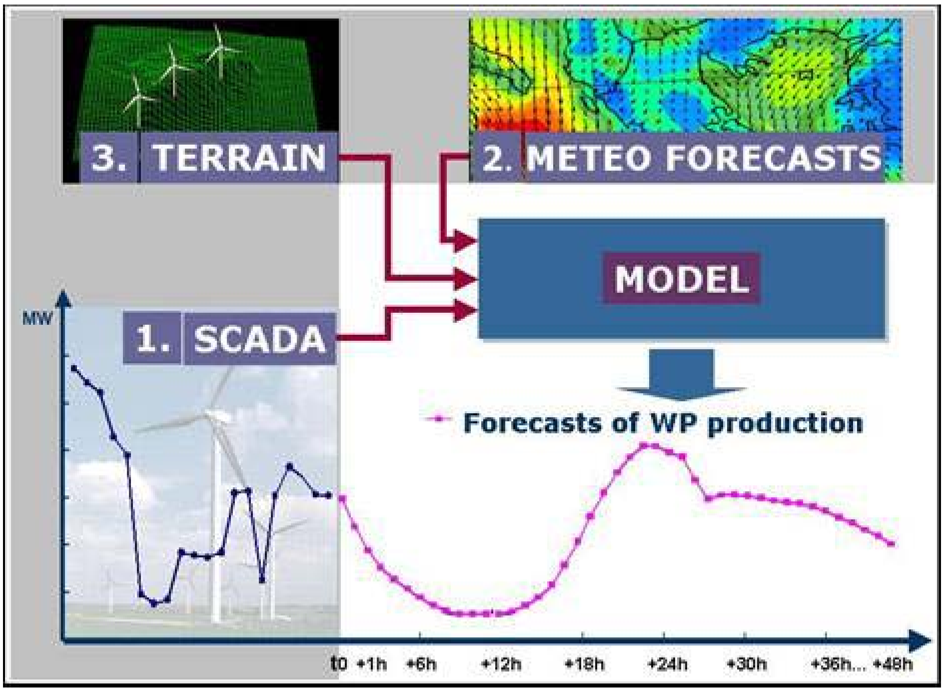


Figure 3.1: The various forecasting approaches can be classified according to the type of input:

(1):	*Short-term statistical approaches can be developed using only SCADASCADA as input.*
(2):	*Long-term physical or statistical modelling with good performance for horizons higher than ~3 hours.*
(2)+(3):	*Long term physical with good performance for horizons higher than ~3 hours.*
(1)+(2):	*Long term statistical with good performance for the whole horizon.*

The "physical" approach for wind power forecasting is based on a detailed description of the wind farm site (orography, roughness, and obstacles), the wind turbines (hub height, power curve, thrust curve) and the layout of the wind plant. The main input is numerical weather predictions (NWP). Model output statistics are developed to account for systematic errors. Weather predictions are however updated only a limited number of times per day by meteorological services. For this reason, the performance of these models is often satisfactory for rather longer (>6 hours ahead) than short-term horizons.

The alternative “time-series”, or statistical, approach includes typical linear models (ARMA, ARX etc) and non-linear ones (i.e. fuzzy-neural network models, artificial neural networks (ANNs), conditional parametric models, etc). These models aim to predict the future by “capturing” temporal and spatial dependencies in the data. The input to these models can be on-line SCADA data and numerical weather predictions (NWP). For look-ahead times more than ~10 hours (mentioned hereafter as “long-term”), NWPs are indispensable for an acceptable performance since they represent weather dynamics that cannot be modelled using only recent on-line data. For shorter horizons, up to ~3-6 hours ahead (mentioned hereafter as “short-term”), time series models can be based exclusively on recent measurements; however even in this case, NWPs as explanatory input improves results. It is noted that a threshold within 3-6 hours is mentioned here as an example rather than a rule, since it depends on the characteristics of a specific wind profile.

Frequent updates of the wind power predictions are necessary for systems with large penetration since they permit to reduce the prediction risk by considering recent available information regarding wind power production or meteorological data.

In the following pages, two statistical approaches developed by Armines’ and ISET’s systems are described in detail. These are the two systems which applied to the UK case study within the DISPOWER project. In addition a brief overview over other prediction tools as well as short conclusion is given at the end of this chapter.

3.2 ISET’s Advanced Wind Power Prediction Tools (AWPT)

3.2.1 Online-Monitoring of Wind power Generation

In addition to wind power forecasts the online acquisition of current wind power data is of interest for a TSO with large wind power penetration. As ISET’s AWPT is based on a so called Online-Model this model is described first in the following.

The most precise procedure for obtaining basis data for generation schedule and grid balance can be considered to be the online acquisition of the power contribution of all wind turbine generators (WTGs) operated in a supply area. However, due to the very widespread installation of WTGs in Germany it is hardly realistic to equip all WTGs with monitoring systems. Hence, online monitoring requires an evaluation model which allows the observed time series of power output of representative wind farms to be extrapolated to the total feed-in from WTGs of a larger net region or control zone. In co-operation with E.ON Netz, the TSO with the worldwide largest wind capacity, ISET has successfully developed an online monitoring system, which is able to provide the current wind power generation of about 6 GW from all plants distributed over the utility supply area . This model transforms the observed power output from 60 representative wind farms with a capacity of about 30% of all turbines, to the total wind power output of all turbines. The determination of the wind farms and the development of the transformation algorithms are based on the long-term experience of the “250 MW Wind“ program and its extensive stock of measurement data and evaluations.

The current wind power production is calculated by extensive equation systems and parameters, which consider various conditions, such as the spatial distribution of WTGs or environmental influences. The observed data from the selected wind farms are thereby transmitted online to the control centre.

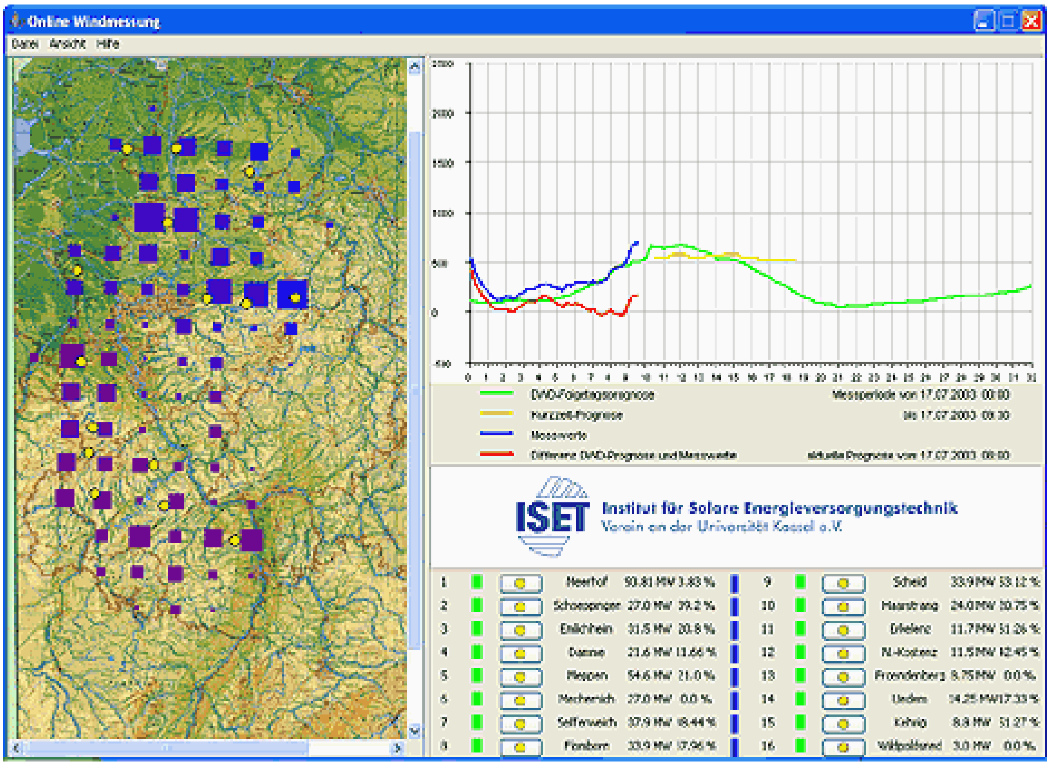


Figure 3.2: ISETs Wind Power Management System

This Online-Model is a basic part of ISET's Wind Power Management System (WPMS) which consists of three tiers. The 2nd and 3rd tier are based on ISET's wind power prediction tool AWPT.

3.2.2 Short-term prediction

In co-operation with E.ON Netz, Lahmeyer International and the Fördergemeinschaft Windenergie, ISET developed a new wind power prediction model, the Advanced Wind Power Prediction Tool (AWPT). This model is effectively based on a hybrid of three proven approaches:

- the accurate numerical weather prediction provided by the DWD (German Weather Service)
- the determination of the accessory wind farm power output, using ANNs
- the extrapolation of the predicted power to the total power input into the utilities' grid by the online-model.

The meteorological component of the prediction tool is based on operational weather forecasting. For this purpose basically the routine updates from the numerical weather prediction model for the investigation area, i.e. the Lokal-Modell (LM) of the DWD are used. The LM is the newest generation model of the DWD and is specifically designed for the handling of the typical small-scale circulation patterns in the German inland area providing results in a spatial resolution of 7x7 km2. The LM results are provided in a one hourly sequence, the updates are calculated twice a day. The following output data of the LM are used for the wind power prediction:

- the wind velocity at 30 m above ground
- the wind direction
- air pressure/ temperature
- humidity
- cloud coverage, which is used for the determination of the atmospheric stability class.

For selected, representative wind farm sites, using i.e. the medium points of these sites as the grid points of the LM, the routine forecast updates are evaluated and the concerning wind farm power output is calculated by Artificial Neural Networks (ANN).

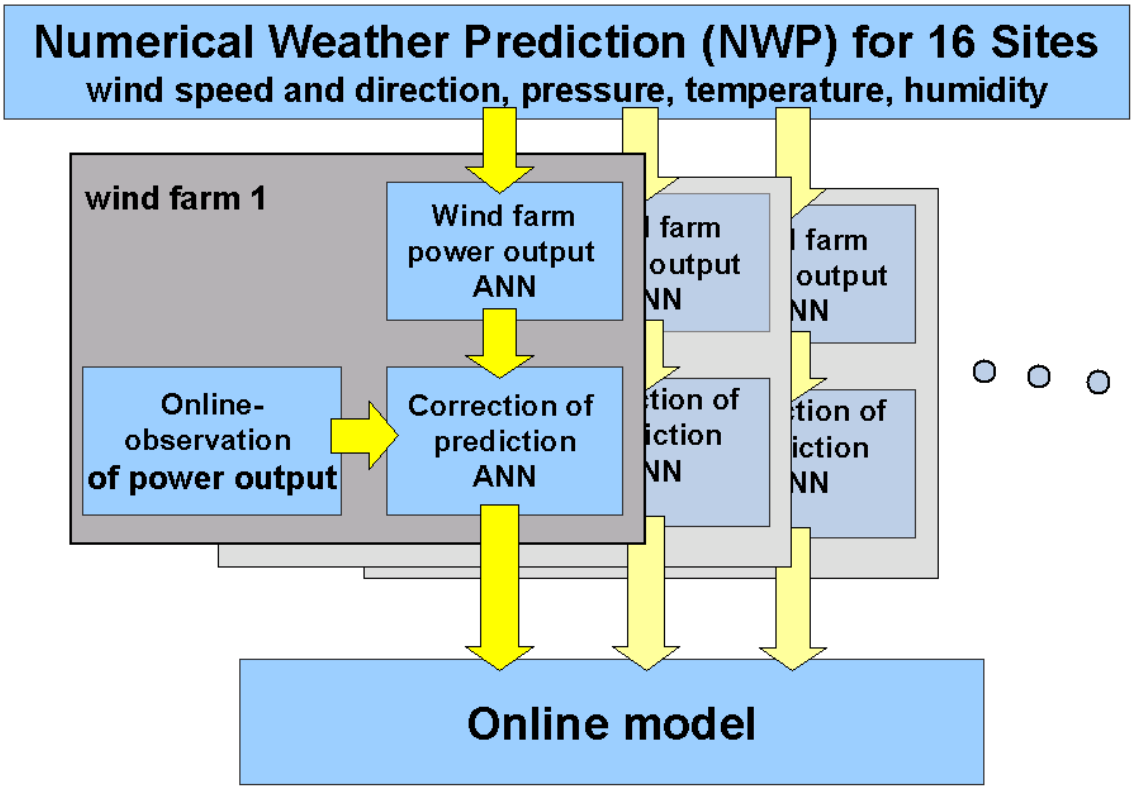


Figure 3.3: ANN inputs

The capability of ANN, for the prediction of the power output of wind turbines has been examined by several institutes. ANN emulate the function of the human brain. Their advantages over standard computing algorithms are that they ‘learn’ from experience, and ‘guess’ or interpolate results, even when their inputs are contradictory or incomplete. Various ANN modules (more than 100) are trained to learn the relationship between variations in the meteorological data and the wind power output, using past wind and power data. By comparing the results with observed power data, the optimal configuration of ANN modules is determined.

The advantage over other approaches is the determination of the physical coherence by using observed data because the real relationship between meteorological data and wind farm power output can hardly be described sufficiently by physical models. Moreover the addition of further parameters does not require expensive modifications of the model. These trained networks compute the predicted wind power output of the representative wind farms which is used for input to the transformation algorithm of the online model. Therefore the online model allows a prediction of the total wind power feed-in of large utility supply areas, based on only a few locations with predicted wind speed. This tool represents the 2nd tier of the WPMS and provides the run of the wind power output for the control area or selected sub-areas twice a day. The resolution is 1 hour and the prediction schedule is 72 hours. The day ahead forecasts, typically used for the load management are computed at 8:00 a.m. and provide the run of wind power generation for the 24 hours of the next day. The total error between predicted and observed power for this prediction is about 9.2 % of the installed capacity for the total wind power in the E.ON area.

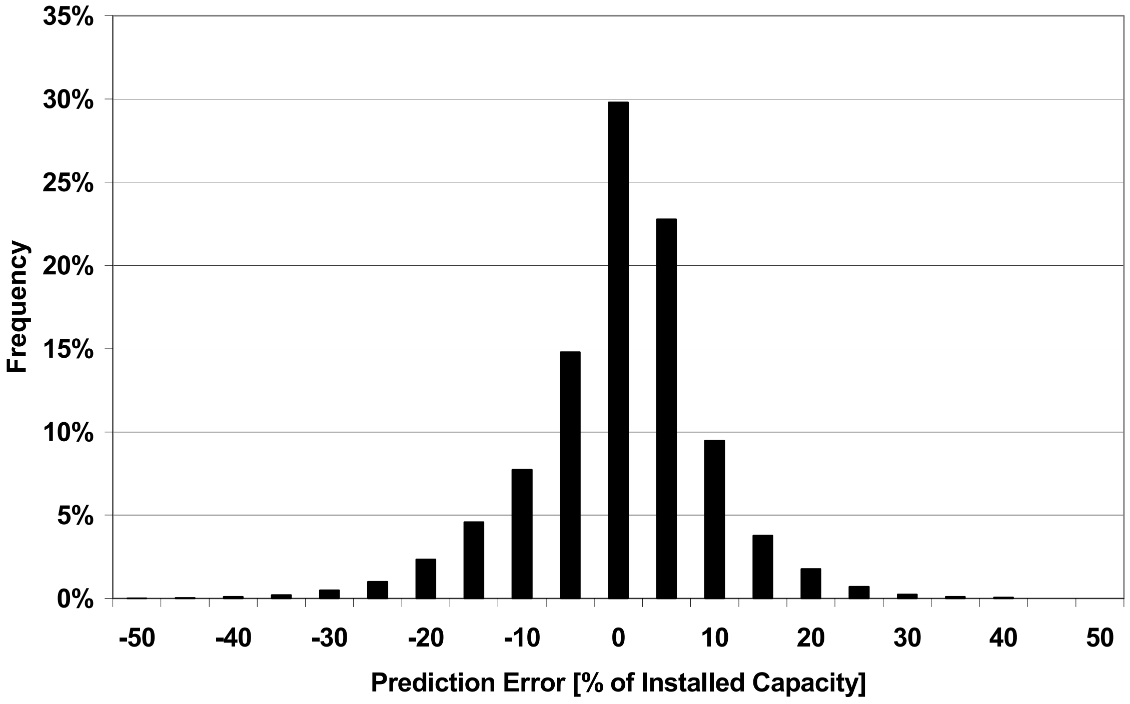


Figure 3.4: Frequency distribution of the forecast error

Figure 4 shows the frequency distribution of the forecast error for the same time period. 97 % of the forecast errors range from –20 % to +20 % of the installed capacity of wind power.

The most frequent cause of forecast errors is caused by poor time prediction of significant large variations of weather situations. Wind power prediction models which are based only on operational weather forecast are not able to correct these deviations. Thus, another module, the 3rd tier, uses the predicted wind farm power output, computed by the 2nd tier in combination with measured wind farm power output of the near past to provide topical updates and adjustments of the prediction. These updates and adjustments of the predicted power output of the next 6 hours are also computed by ANN and can be carried out at any time. Table 3.1 shows the accuracy of the 3 – 6 hour forecasts in comparison to the persistence model.

Table 3.1: Forecast errors

Forecast	Time Period [h]	RMSE [%]	Correlation
Persistence	3	6.5	0.92

	4	8.0	0.88
	5	9.4	0.84
	6	10.5	0.80
AWPT 3	3	5.2	0.95
	4	5.7	0.94
	5	6.1	0.93
	6	6.3	0.93

The advantages of these models can be summarized as follows:

- the model architecture and the combination of online-monitoring and prediction model allows universal applications
- high precision and minimum computation time
- easy adaptation to other RES.

Since July 2001 the model is in operation at E.ON and it was installed at two other German TSOs, RWE Net and Vattenfall Europe Transmission GmbH in 2003. Furthermore it is used to calculate the horizontal wind energy exchange between the German TSOs.

3.3 The ARMINES Wind Power Prediction System

ARMINES has developed work on short-term wind power forecasting since 1993. Initially, short-term models for the next 6-10 hours were developed based on time series analysis to predict the output of wind farms in the frame of the LEMNOS project (JOU2-CT92-0053). The developed models were integrated in the EMS software developed by AMBER S.A and installed for on line operation in the island of Lemnos.

In the frame of the project CARE (JOR-CT96-0119), more advanced short-term models were developed for the wind farms installed in Crete. In the ongoing project MORE-CARE (ERK5-CT1999-00019), ARMINES developed models for the power output of a wind farm for the next 48/72 hours based on both on-line SCADA and Numerical Weather Predictions (meteorological forecasts). The developed forecasting system can generically accept as input different types of meteorological forecasts (i.e. Hirlam, Skiron etc.).

The wind forecasting system of ARMINES integrates:

short-term models based on the statistical time-series approach able to predict efficiently wind power for horizons up to 10 hours ahead.

longer-term models based on fuzzy neural networks able to predict the output of a wind farm up to 72 hours ahead. These models receive as input on-line SCADA data and numerical weather predictions.

combined forecasts: such forecasts are produced from intelligent weighting of short-term and long term forecasts for an optimal performance over the whole forecast horizon.

The developed prediction system is integrated in the More-Care EMS software and is installed for on-line operation in the power systems of Crete and Madeira. A stand alone application of the wind forecasting module is configured for on-line operation in Ireland.

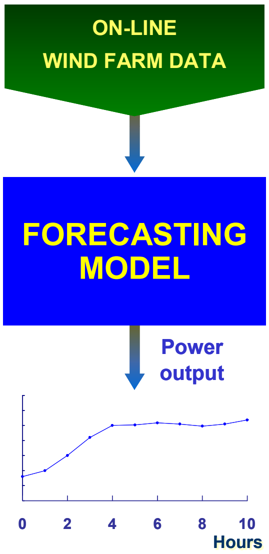


Figure 3.5: General configuration of the ARMINES short-term wind forecasting model

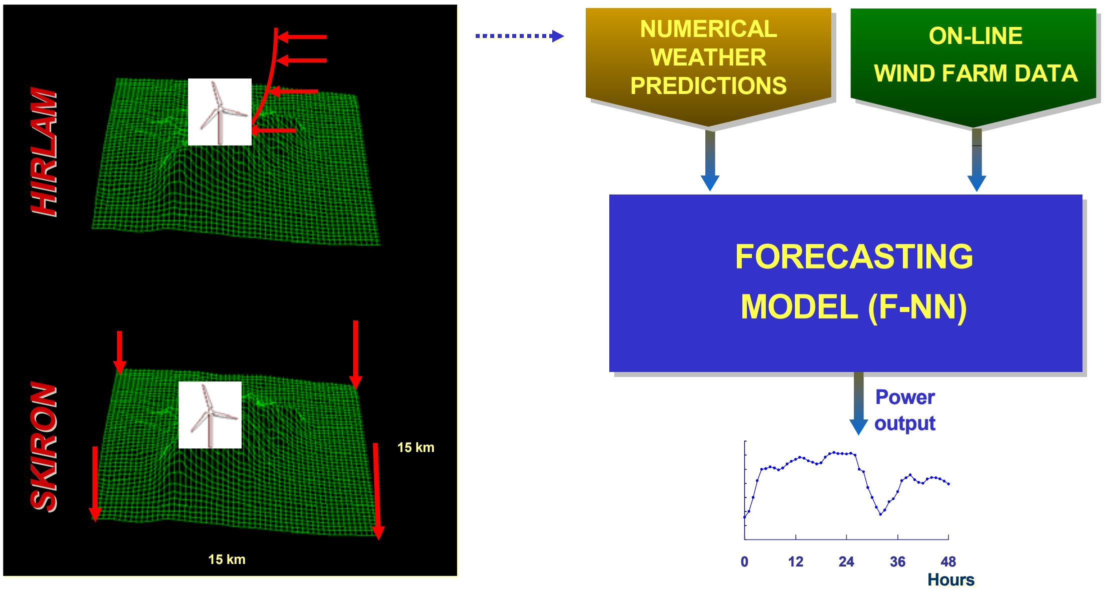


Figure 3.6: General configuration of the ARMINES long-term wind forecasting model.

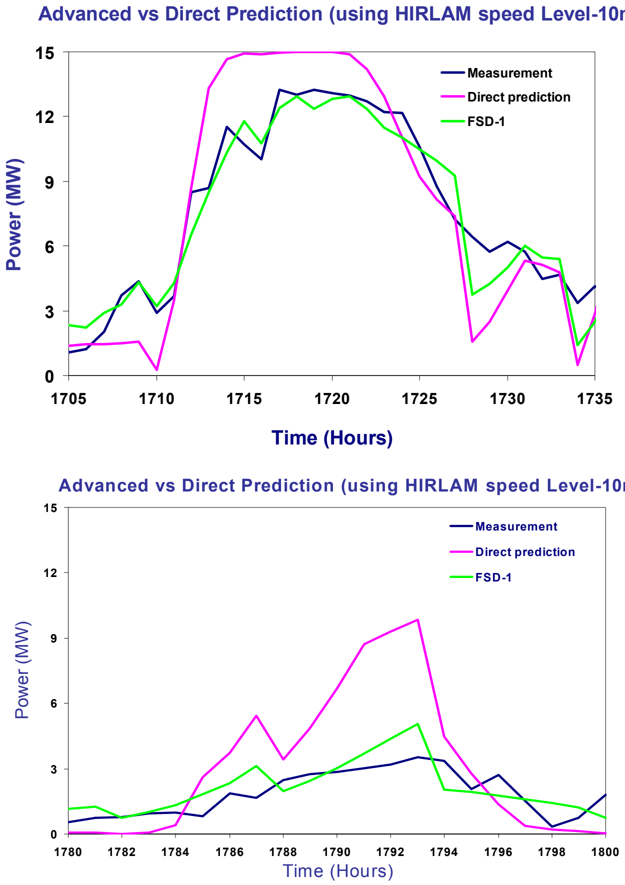


Figure 3.7: Examples of predictions several hours ahead for a wind farm in Ireland using the ARMINES model (FSD-1).

In the frame of past projects, ARMINES has developed research belonging mainly to the statistical approach. More specifically, models based on adaptive fuzzy neural networks have been developed and evaluated against simple models such as persistence. These models are autoregressive models with exogenous variables as input. Appropriate configurations were developed for short and long-term forecasting considering SCADA input and eventually numerical weather predictions.

In previous projects ARMINES has evaluated the performance of various statistical methods for wind power forecasting such as:

- linear autoregressive models,
- radial basis functions,
- wavelet networks,
- artificial neural networks (ANN),
- recurrent high-order neural networks, and finally
- adaptive fuzzy-neural network (F-NN) models.

F-NNs, originally used here for wind forecasting, were found to outperform the other approaches and for this reason they were adopted for implementation in on-line software.

Adaptive F-NNs are applied here for both "short-term" and "long-term" wind power prediction. The adaptivity property stands for the capacity of the model to fine-tune its parameters during on-line operation. This is an important requirement for a non-stationary process like wind speed or power. Adaptivity of the model compensates changes in the environment of the application that may happen during the lifetime of a wind farm. Such changes can be changes in the number of wind turbines (extension of the wind farm, maintenance or availability of the machines that is usually not available through SCADA), in the performance of the wind turbines due to aging, changes in the surrounding of the wind farm (i.e. vegetation), or changes in the configuration of the model used to produce the NWPs.

The core F-NN model is generic and can be trained on appropriate input depending on the final use. It covers the following two families of models:

1. Model configurations for short-term prediction (<6 hours ahead). Short-term predictions are adequate for small power systems with fast conventional units. In that case planning functions are performed in horizons shorter than 10 hours. NWPs, either due to their cost, or due to the fact that they are not updated frequently are of limited use in these cases. The evaluation of short-term model configurations is out of the scope of this report. Such configurations have been tested and implemented by ARMINES in island systems such as Lemnos and Crete in Greece, The Azores and Madeira in Portugal.
2. Model configurations for "longer-term" prediction (0-48 hours) considering numerical weather predictions as input. Such predictions are required for interconnected or large autonomous power systems. Time-series models that consider meteorological information as input, as the one presented below, outperform short-term models (improvement up to 40% w.r.t. persistence) for horizons up to 10 hours.

In the frame of the offline evaluation of the prediction models for the DISPOWER project, we focus on the second model configuration that we describe more specifically in the next paragraph. The long-term model has been evaluated for wind farms in seven countries (UK, Denmark, Greece, Spain, Ireland, Germany, France). It has been implemented for online operation in Greece for the prediction of the output of 5 wind farms and in Ireland for 11 wind farms.

3.3.1 General description of the Armines prediction module

For “long-term” horizons up to 24 or 48 hours ahead, it is necessary to include numerical weather predictions (NWP) as explanatory input to the model in order to have an acceptable performance. NWPs include usually wind speed, direction and temperature at 10 m, as well as at several altitude levels defined by atmospheric pressure. NWPs can be provided for the geographical coordinates of the wind farm or for a grid of four points surrounding the farm. In the second case, the spatial resolution of the NWP model is of primary importance. Meteorological models with high resolution are often more accurate but require high computation time to produce forecasts, and as a consequence, they do not update frequently their output (i.e. 1-4 times per day). In contrast, forecasts from low-resolution NWP models are more frequently available.

The ARMINES model receives on-line data as well as NWPs as input to predict the total production of each wind farm for the next 48 hours. These forecasts are updated every hour based on the most recent wind power measurements. Wind power data are necessary for the on-line updating procedure, independently if they are used or not as input variables to the model. The updating procedure permits mainly a good performance of the model for the first hours (i.e. 1-6 hours) of the considered horizon. Model configurations that do not update their forecasts based on recent wind power data were found to perform worse than persistence in look-ahead times up to 6 hours ahead. Finally, the consideration of on-line information other than wind power (i.e. wind speed or direction), was not found to contribute in the accuracy of the results. The general scheme of the model is shown in Figure 3.8.

The aim of the prediction model is to capture the relations between input (meteorological information, on-line data) and output (future total wind farm power). Such mapping includes the following implicit relations:

- Temporal correlations between past and future data of the process (autoregressive aspect of the model).
- Conversion of wind speed (meteorological predictions) from the height or the atmospheric level they are given to the hub height of the wind turbines.
- Spatial projection of the meteorological wind speed forecasts from the NWP grid points (e.g. 15x15 km) to the level of the wind farm (“downscaling”).
- Correction of the wind farm output for factors affecting the total production (i.e. array effects, effect of wind direction etc).

The advantage of a model such as the fuzzy neural networks model, compared to models based on the “physical” approach, is that it permits to avoid all the above intermediate modelling steps. Moreover, its adaptive mode can compensate situations like the ones explained in the previous Section.

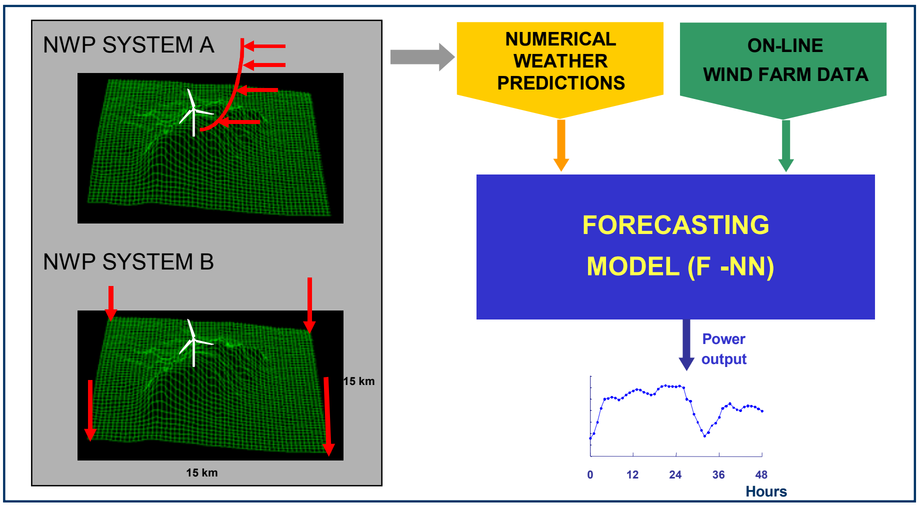


Figure 3.8: General scheme of the “long-term” prediction model with examples of two configurations of NWP systems used as input (Skiron, Hirlam).

3.3.2 The MORE-CARE EMS Software

ARMINES has participated in a number of projects (Lemnos, CARE, MORE-CARE) that had as their objective the development of advanced EMS (energy management system) software for autonomous power systems. These projects have treated the problem of wind prediction as part of the general management problem of a power system with high wind integration.

The final output of the above-mentioned projects is the MORE-CARE EMS software. This includes a number of various modules for Wind Power Forecasting, Load Forecasting, Hydro Forecasting, Unit Commitment, Economic Dispatch, Dynamic Security Assessment etc. This software is under installation for on-line operation in the following power systems:

- In the island of Crete in Greece by PPC.

- In the island of Madeira in Portugal by EEM.
- In the power system of Ireland by ESB.

The application in Ireland is of particular interest since the MORE-CARE software is configured to operate as a stand-alone Wind Power Forecasting System providing forecasts for 11 wind farms in Ireland.

The MORE-CARE approach is an integrated one since the software not only gives the possibility to produce wind predictions but also to use them directly as input to other advanced modules such as Unit Commitment, Economic Dispatch or Security Assessment to provide on-line optimal solutions for the management and the security of the power system. In this way, the software consists also a means to evaluate on-line the benefits from accurate wind power prediction.

Although the management functions of MORE-CARE are developed for autonomous systems, the wind forecasting functions are general and applicable in large interconnected systems as shows the stand-alone application in Ireland.

On the other hand, the MORE-CARE approach provides a reference for the integration of renewable resources prediction software (wind and small hydro) within an EMS system. This approach can be useful in the frame of the DISPOWER project.

3.3.3 Experience with prediction tools in France, Greece, Portugal and Ireland

France

At the present time wind penetration in France is very low (in the order of 100 MW). For this reason wind prediction is not currently a priority issue for the wind farm operators since they are able to introduce their production in the grid without particular difficulties.

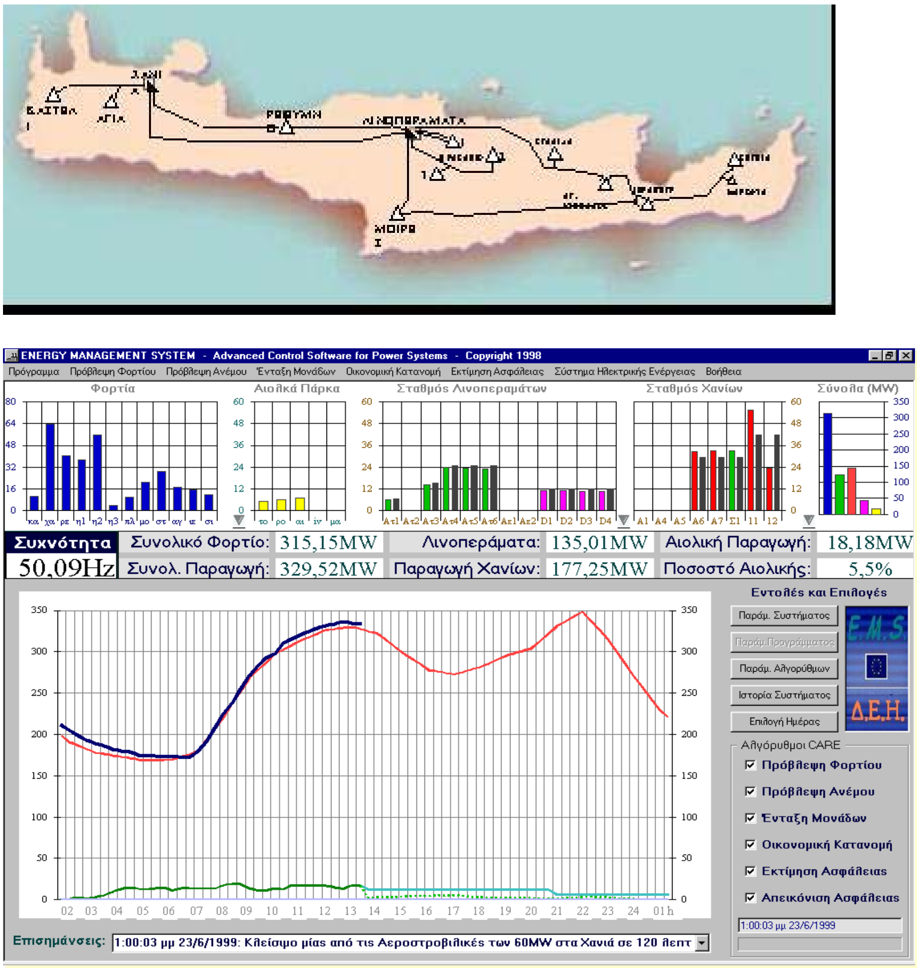
However, in the next years the projected development of wind energy is expected to emerge the use of wind power forecasting tools. In order to anticipate this need, EdF participates in the European Project Anemos (NNE5-2001-000857), which has as objective the development of a next generation advanced wind power forecasting system appropriate for large – scale wind prediction. This system will be installed at wind farms piloted by EDF.

ARMINES/Ecole des Mines de Paris has developed the wind forecasting system described in the previous section. This system has been integrated in the MORE-CARE EMS software and is installed for on-line operation at Crete, Madeira and Ireland.

Greece

Currently only PPC in Crete operates a wind power forecasting tool. Crete is the outstanding site in Greece for high wind power penetration. 80 MW of wind power are installed on the island where the demand varies between 170-450 MW throughout the year. Wind penetration reaches high levels. Furthermore, the fact that the network is an autonomous one, makes the use of wind power forecasting necessary for an economic and secure integration of wind farms in the grid.

Currently, the MORE-CARE system is installed and operated by PPC in Crete and provides wind power forecasts for all the wind farms for a horizon of 48 hours ahead. These forecasts are based on numerical weather predictions provided by the SKIRON system, which is operated by IASA. On-line data are provided by the SCADA system of the island.



Συχνότητα 50,09Hz

Συνολικό Φορτίο: 315,15MW

Συνολ. Παραγωγή: 329,52MW

Λινοπεράματα: 135,01MW

Παραγωγή Χανίων: 177,25MW

Αιολική Παραγωγή: 18,18MW

Ποσοστό Αιολικής: 5,5%

Αλγόρυθμοι CARE
- ☑ Πρόβλεψη Φορτίου
- ☑ Πρόβλεψη Ανέμου
- ☑ Ένταξη Μονάδων
- ☑ Οικονομική Κατανομή
- ☑ Εκτίμηση Ασφάλειας
- ☑ Απεικόνιση Ασφάλειας

1:00:03 μμ 23/6/1999

Επισημάνσεις: 1:00:03 μμ 23/6/1999: Κλείσιμο μίας από τις Αεροστροβιλικές των 60MW στα Χανιά σε 120 λεπτ

Figure 3.9: Userinterface of the MORE-CARE application in Crete.

The software permits both **monitoring** of the conventional and renewable units and also **forecasting** of load, wind power and hydro resources.

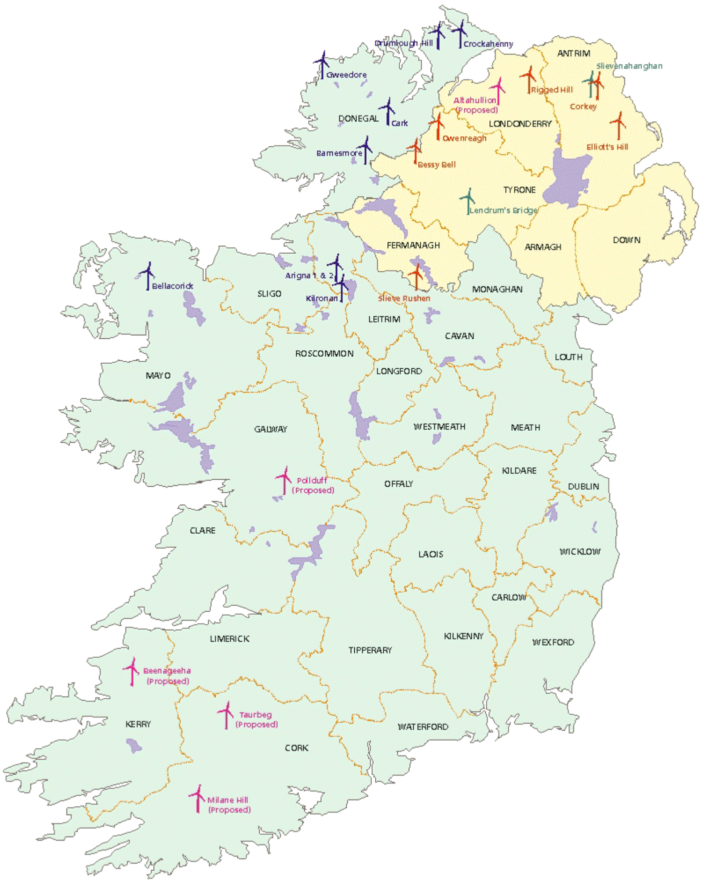
Portugal

In continental Portugal no wind power prediction tools are currently operated. However, as in Crete, the MORE-CARE system is operated by EEM and provides forecasts for the production of the wind farms on the island of Madeira. The prediction modules provide forecasts for the short-term up to 8 hours ahead using on-line SCADA data as input. Moreover, MORE-CARE provides **predictions for the operation of the river hydro** installations of the island.

Figure 3.10: Wind farm on the Island of Madeira.

Ireland

The MORE-CARE software is installed in a stand-alone configuration for providing predictions for the power output of 11 wind farms installed at the island. The software is operated by ESB. It is using both on-line measurements from the wind farms as well as HIRLAM numerical weather predictions.



3.4 Prediktor

The “Prediktor” system has been developed by Risø National Laboratory, Denmark. The idea is to use physical models as far as possible. One main input is the large scale flow modelled by a Numerical Weather Prediction (NWP) model, called HIRLAM. The wind is transformed to the surface level using the geostrophic drag law and the logarithmic wind profile. As we zoom in on the site more and more detail is required, this detail is provided by the Risø WAsP program. WAsP takes local effects (lee from obstacles, effect of roughness and roughness changes, and speed-up/down of hills/valleys into account. To take the shadowing effects of turbines in a wind farm into account the Risø PARK program is used. Finally to take any effects not modelled by the physical models and general errors of the method into account two model output statistics (MOS) modules are used.

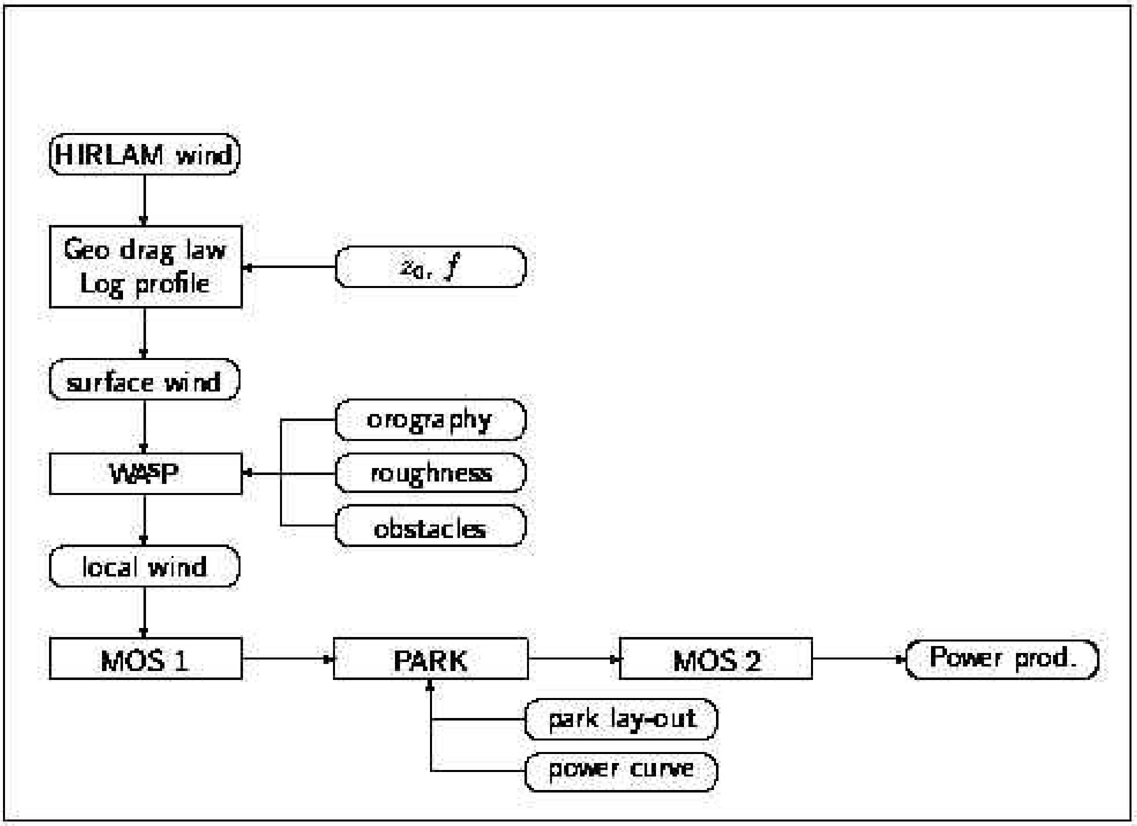


Figure 3.11: The schematic run of the Prediktor system

The model runs twice a day generating predictions 36 hours ahead for several wind farms in the supply area. Each wind farm power prediction can also be scaled up to represent a region instead of just itself. To get an estimate of the accuracy of the model the predictions are compared to those of the *persistence* model, which is a very simple model stating that;

P(t+l)=P(t)

where P(t) is the production at time t and l is the look ahead time. This model could popularly be called the “what-you-see-is-what-you-get” model. Despite its seeming simplicity, this model describes the flow in the atmosphere rather well, due to the characteristic timescale of weather systems; it is often experienced that the weather in the afternoon is the same as it was in the morning. On a short prediction horizon of only a few hours it is a rather difficult model to beat.

The following results of the comparison between the prediction and persistence models can be seen:

- the prediction model outperforms the persistence model after six hours.
- the mean absolute error of the prediction model is around 15% of the installed capacity. A well predicted wind farm has a scatter as low as 10% and a not so well predicted one up to 20%.
- the decay of the performance of the prediction model is very gentle, over the 36 hour time-span the error is only increased by less than 10%.

3.5 Wind Power Prediction Tool (WPPT)

Another philosophy in predicting wind power is implemented in the Wind Power Prediction Tool (WPPT), developed as a co-work between ELSAM and the Department of Mathematical Modelling (IMM) at the Technical University of Denmark (DTU). WPPT's statistic methods are applied for predicting the expected wind power production in larger areas using online data covering only a subset of the total population of wind turbines in the area. The approach is to divide the area of interest into sub-areas each covered by a reference wind farm. Predictions of wind power with a horizon from ½ hour up to 36 hours are then formed using local measurement of climatic variables as well as meteorological forecasts of wind speed and direction. The wind farm power prediction for each sub-area are subsequently scaled-up to cover all wind turbines in the sub-area before the predictions for sub areas are summarised to form a prediction for the entire area.

Wind speed, wind direction, air temperature, and the power output at the reference wind farms are sampled as 5 minute mean values to provide input data to WPPT. In addition to that meteorological forecasts are used as input to the models. This forecasts are provided by the Danish Meteorological Institute (DMI) using HIRLAM. The forecasts are updated every 6 hours and cover a horizon of 48h ahead with a 1 hour resolution. The approach taken in WPPT is to use statistical methods to determine the optimal weight between the online measurements and the meteorological forecasted variables.

The first version of WPPT went in operation in October 1994. In this version no NWP data were used but predictions were based on statistical analysis on measurements of only seven wind farms. The predictions were inadequate for horizons larger then 8 hours due to the following reasons:

- bad reliability of measurement equipment
- to few wind farms included
- lack of meteorological forecasts.

A new project was started in 1996 with the aim to get better predictions by including more wind farms, better reliability of equipment and getting good meteorological forecasts. This system is now running with good results on all the Danish utility's dispatch centres. The accuracy depends, of course, on the horizon, and a typical forecast error on a 24 hour forecast is around 10-15% for a single wind turbine farm. However it is clear that after a summation to larger areas (e.g. Jutland) then the error is reduced considerably.

3.6 Previento

Previento is the name of a forecast system, which has been developed recently at the University of Oldenburg. It provides the power prediction for a larger area, e.g. whole of Germany for the next two days. It works in a similar way to the Prediktor system. The German version uses data of the German Weather Service instead of HIRLAM data. Furthermore it provides an estimation of the possible error depending on the weather situation.

3.7 Zephyr

A new program for short-term prediction of wind energy is under development in Denmark. The partners are Risø and IMM for the development of the system, and all Danish utilities as users. The new software is called Zephyr, and based on Java2, enabling high flexibility. New prediction models are enabled through the availability of new input data. Zephyr merges the two Danish models Prediktor and WPPT. The combination will ensure that good forecasts are given on all prediction horizons from the short range (0-9 hours) to the long range (36-48 hours). This is because the IMM approach uses online data and advanced statistical methods, which is advantageous in the short horizon, while the use of meteorological models like the HIRLAM model of the Danish Meteorological Institute is advantageous in the long term forecasts. An intelligent weighting of the results of both modelling branches then gives the result for the total supply area of the customer. Whether these really will improve the forecasts significantly, can only be guessed at this stage. However, due to the further development of the existing models, the new model will probably have better performance than the previous generation. A first version of Zephyr is already installed at utilities. A final version was scheduled for 2002.

3.8 HIRPOM

Since a couple of years the Sustainable Energy Research Group (SERG) part of the Department of Civil & Environmental Engineering at University College Cork (UCC), at Cork in Ireland is working at prediction systems especially in complex terrain such as that found in Ireland.

A recent study demonstrated that standard NWP models presently available cannot forecast local winds accurately in Ireland due to inadequate representation of the topography, especially the mountainous areas and the coastline. It was found that a resolution of 5km or less is required to describe the local effects in such a terrain adequately. In addition to these local requirements, an optimal prediction system over Ireland must be able to forecast the development of lows and fronts on a scale of several 1000 km. The large scale flow pattern also controls the local winds and is therefore of equal importance. Combining traditional areas of expertise with a new area requires new strategies of research and is therefore quite challenging.

The mean wind speed is the most important parameter for power predictions. However, density, turbulence, wind shear and direction changes are also have to be taken in account for an accurate prediction. They are not more difficult to predict than the mean wind speed in the NWP model. In fact density and vertical wind shear are modelled more accurately than wind speed. Thus, it is suggested to also include these parameters in the calculations. However, this can only be done with a much higher temporal resolution of the model.

The SERG in UCC and the Danish Meteorological Institute (DMI) have started to tackle the problems associated with real-time forecasting of wind energy. Therefore, SERG and DMI decided to demonstrate in a collaborative work a real-time setup of wind energy prediction with a new approach. This new approach called HIRPOM incorporates power predictions inside the numerical weather prediction model HIRLAM. The advantages of this approach are the possibility of modelling with high time resolution and to parameterise the wind power on a physical basis. The results confirm that a statistical approach is required to deal with local errors. These errors are a result of the mismatch of the model's surface representation and the actual roughness and topography. They can be minimised by adjusting model output to local conditions on a statistical basis for wind power alone. Another source of errors are large-scale atmospheric errors. The main contribution is due to incorrect model phases of passing fronts and lows. This problem was not tackled in the present study. In complex terrain the gain in accuracy could be found is very encouraging although a lot of research still has to be done.

3.9 SIPREÓLICO

SIPREÓLICO is a statistically based prediction tool developed by the University Carlos III, Madrid and the transmission system operator Red Eléctrica de España (REE). It is presently a prototype that provides predictions 24 times a day with a time horizon of up to 36 hours. To generate them, meteorological forecasts, as well as online power measurements, are used as inputs to time series analysis algorithms. These predictions are already being employed by REE for online system operation. SIPREÓLICO first produces predictions for single wind farms, once the predictions are obtained for every farm, they are aggregated in zones and the final production prediction for the Spanish peninsular system is found.

For a given wind farm, SIPREÓLICO uses four types of inputs. These are the characteristics of the wind farm, historical records of simultaneous incoming wind and output power to perform a real power curve, online measurements of power output, and meteorological predictions provided by HIRLAM. The algorithms that SIPREÓLICO utilises to generate the predictions depend on the types of input available. Input data may be Basic, Additional, or Complete. Basic data are those that are available for every wind farm, and consist on the standard power curve and meteorological forecasts. Additional data are the Basic data plus the real power curve. Complete data is the Basic plus online measurements of generated energy.

If only Basic data are available, a prediction is made using the wind speed predictions and the standard power curve obtained as a sum of the existing turbines. With Additional data, historical records of incoming wind and output power exist for a wind farm. Then, a real wind farm power curve can be found, and more accurate predictions may be obtained. In this case, wind direction forecasts, as well as wind speed can be considered. When online measurements are available, a statistical time series analysis is performed. This method is the most accurate and it is the main part of SIPREÓLICO. Actually, more than 80% of the wind farms connected to the grid supply online information. Therefore, accurate predictions can be generated for most of the farms. The performance of SIPREÓLICO in the Southern Andalucía area is above the average. This good performance can be explained by the quality of HIRLAM data for that area. On the other hand, the performance of SIPREÓLICO in Navarra is below the average. The wind plants in Navarra are far from the coast and also have a very complex terrain. This location can explain the observed large differences between the measured wind using the farm anemometer and the HIRLAM predictions. This effect provokes poor predictions at horizons larger that twelve hours. The performance for the total peninsular system is quite good however. The aggregation of individual predictions has a positive effect in the performance of SIPREÓLICO.

3.10 Comparison of the approaches used

More or less one can divide the methods in two classes – systems which use numerical weather prediction (NWP) and systems using online measurements and analyses of the statistical behaviour. In general the results show that NWP based systems are better on longer prediction times e.g. 6 to 48 hours while statistical systems are usually better on the short time frames ½h to 6h.

The statistical tools use online measured data of the last few hours to predict the wind power of the next 1 to 8 hours. WPPT's first version was a pure statistical system. It provided good predictions for a short horizon up to 8 hours but wasn't useful on longer predictions. Soon its second version was developed using the NWP data as an input as well. This one gave much better results on longer prediction times.

Table 3.2: Overview of wind power prediction systems.

Prediction Model	**Developer**	**Method**	**Operation**
Prediktor	Risø	Physical	-
WPPT	IMM; University of Copenhagen	Statistical	≈1GW, Denmark
Zephyr, Combination of WPPT and Prediktor	Risø and IMM	Physical, Statistical	-
Previento	University of Oldenburg, Germany	Physical	-
HIRPOM	University College Cork, Ireland Danish Meteorological Institute	Physical	Under development
SIPREÓLICO	University Carlos III, Madrid Red Eléctrica de España	Statistical	≈ 4 GW, Spain
AWPPS	Armines	Statistical, Fuzzy Logic	Several wind farms
AWPT	ISET	Statistical, ANN	≈ 10 GW, Germany

Prediktor and HIRPOM are using only NWP data. To optimise the systems with MOS measurement data are needed but they don't need to be collected online. This makes the data collection much easier.

Previento also mainly use NWP data but it can be extended with online measurements.

Zephyr, SIPREÓLICO, AWPPS and AWPT are using the combination of NWP and online measurements as input data. This systems use the advantage of both approaches. On one hand there is the high accuracy of the NWP on a longer prediction horizon (up to 48 hours). On the other hand there is the advantage of the online measurement for a few hour forecast. However, the online measurements are needed cause some extra expenses. The measured farm has to be chosen wisely to be representative for the whole area and the equipment needs to be very reliable.

To calculate the prediction error first the measured wind power is needed. It is not required to have the data online but as accurate as possible. To observe a single wind farm is quite easy but to get the sum power of a large supply area usually some kind of an upscaling algorithm is needed. However, it depends on the structure of the wind farms. In Denmark and Germany for example one can find a lot of small wind farms as well as single WTGs, which makes it difficult to get the total power by measurement. In Spain there are fewer but larger wind farms, which make it easier to get real measurement data without upscaling. It is evident that a higher ratio between measured and total power increases upscaling accuracy on one hand but raise the effort of data collection on the other hand. The Zephyr system is planned to get the measurement data from all the wind farms in the area, while Prediktor and WPPT are using only some tens of big wind farms in the area. AWTP is using 35 wind farms in the E.ON area (16 at RWE and 15 at VET).

To calculate the prediction error different error functions are used. The most common is the Root Mean Square Error normalised to the installed wind power (NRMSE), but also the correlation coefficient is very useful.

From the utility point of view other criterions are of interest e.g. an overestimation of wind power causes a lack of power in the system so the utility has to buy expensive regulation power on the spot market. On the other hand an underestimation is not so expensive for the utility. However, as long as the predicted and the true wind power is under a certain amount (a couple of hundreds of MW in a TSO area) an error doesn’t count at all. For research institutes the first step is to get the RMSE as low and the correlation as high as possible. The optimisation to the utilities needs is another step and has to be done afterwards.

All the systems first calculate the power output of single wind farms and than use some kind of upscaling algorithm to get the sum power of the whole supply area. Regardless of the system in use the RMSE for a single wind farm is between 10% and 20%. After upscaling to the sum power the RMSE drops down under 10% due to the smoothing effects of adding different signals. The larger the area the better the overall predictions is going to be.

The comparison in quality of the systems is very difficult because of the different areas they are used for. The Danish systems are running in a mostly flat terrain which makes an accurate NWP much easier but on the other side there are fewer slack periods and the average wind power output is higher which increases the overall error. In Germany the NWP especially in the lower mountain area is much more difficult but periods of low wind power especially in the summer decreases the RMSE.

It’s impossible to decide which is the best of the system described above. It always depends on the user’s needs and his abilities. Zephyr, AWPT, and SIPREÓLICO are probably the best over the whole prediction horizon from 1 to 48 hours. However, the efforts involved in setting up the systems are high, especially for collecting the online data.

Systems using WASP, such as Prediktor or Previento need the exact knowledge of the location and environment of the wind farm they are predicting. Furthermore they need high computation time to transform the geostropic wind speed down to the hub heights of the WT’s with WASP. However, the statistic models like WPPT and AWPT need some time to learn the correlation between wind and power while they are set up. On the other hand these models need a minimum of operation time.

On all prediction systems poor forecasts have been seen in the following situations:

- very fast developing depressions running fast over the area.

- very high wind situation (storms) when windmills are stopped
- very local weather changes (thunderstorms) give problems to the upscaling
- bad measurements that are not automatically detected (only at systems using online data)
- delayed or missing forecasts from the weather services
- poor meteorological forecast data (very often a time shift between forecast and real data causes a large error).

The biggest potential for improving the predictions' accuracy lies in the improvement of the NWP. A model can hardly be better than its input data. Only the systems using online data can improve the NWP based forecast, but only on a small horizon of a couple of hours ahead.

4 UK case study

4.1 Description of the UK Case Study

The objective of the subtask 5.3b) was the achievement of all requirements to improve the existing wind power prediction models, developed at ISET and Armines for the application on six wind farms in the UK. The results of subtask 5.3.a (further research for the improvement of existing methods) were used to implement all required features for the application in DG. The prediction models will provide wind power forecasts for wind farms operated by National Wind Power, a large owner and operator of wind farms, and part of a major electricity company within the UK, National Power. IT Power collected all required data and information for the model improvement, i.e. time series of wind farm power output and basic data of the wind farms. Meteorological forecast data were provided by UK Met Office. Within the DISPOWER project ANNs and FNN have been trained with data from the past to provide power forecasts for the wind farms.

4.1.1 Numerical Weather Prediction (NWP) and Power Measurement (SCADA) Data.

The data available for this case study are production SCADAand NWP data. The SCADA data are mean hourly production values.

The NWP data come from the UK Met Office Mesoscale model. For each site data from four grid points surrounding the farm were selected. If the site fell close to a grid point, five grid points were selected. The co-ordinates used for these sites are presented below. The NWP data was updated four times a day without overlapping of the datasets. Because of this, only two-hour ahead predictions were considered.

Furthermore, in an operational setting, updated NWP data are available with a delay of two hours. As a result 2-hours ahead forecasts can only be generated four times in every six-hour interval. This fact was taken into account in the offline evaluation.

To train and test the F-NN model the datasets were split in two subsets. The data split proposed by ISET was followed and consisted in using one out of two consecutive days for training and one for testing, and so forth throughout the dataset.

To evaluate the model's performance the following criteria were considered:
- Root Mean Square Error (RMSE) between measured and predicted wind farm power output. Here the Normalised RMSE (NRMSE) is given as a percentage where normalisation is based on the Nominal wind farm power.
- Correlation (CORR) between the curves of measured and predicted values
- Mean Bias Error (MBE), difference between averages of predicted and measured values
- Energy Lack (ENL), sum of all positive prediction errors ($Ppred - Pmeas > 0$)
- Energy Surplus (ENS), sum of all negative prediction errors ($Ppred - Pmeas < 0$)
- Frequency Distribution of the single difference between predicted and measured power.

In addition to the above criteria the Normalised Mean Absolute Error (NMAE) is given. The NRMSE weights more large errors while in the NMAE all errors have the same importance. For this reason the NMAE has usually lower values than the NRMSE.

The grid points selected from the UK Met Office mesoscale model are based upon the locations of the wind farm sites; where a site fell very close to a grid point, and then five points were selected.

The data have been extracted for the following period: 01 January 2001 to 31 July 2002 from the Standard Pressure Level Mesocale Operational NWP Archive (Unified Model v4.5+). The fields used are as described below.

4.1.2 Wind Farm Sites.

Table 4.1: Geographical coordinates of wind farms of the case study.

Windfarm	Country	NG Eastings	NG Northings	Lat (dec deg)	Lon (dec deg)
Carno	Wales	291566	295690	52.5479	-03.5993
Llyn Alaw	Wales	236538	387515	53.3589	-04.4566
Bears Down	England	190123	067749	50.4713	-04.9579
Bryn Titli	Wales	293284	275176	52.3639	-03.5674
Taff Ely	Wales	298156	186308	51.5660	-03.4695
Kirkby Moor	England	325604	483555	54.2421	-03.1417

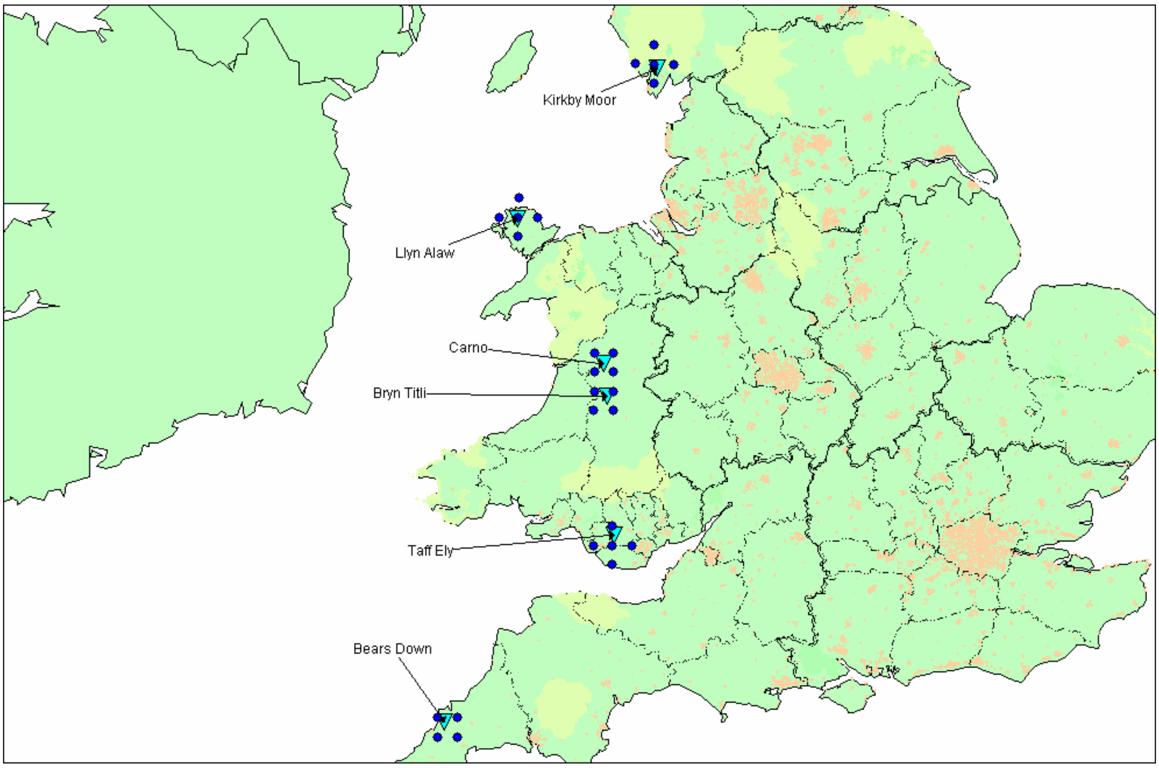


Figure 4.1: Windfarm sites with surrounding grid points of the numerical weather model.

4.1.3 Data

National Wind Power data

National Wind Power have provided data on the actual power generated by six of their wind farms over the period January 2001 to July 2002. This data is then used to compare with the predictions from the models.

For three sites, good quality half hour data is available from data loggers connected to a meter specifically to provide half hour energy data. The other three sites have 10 minute average power data from the SCADA systems at the wind farms.

Sites using half hourly data:
- Bryn Titli
- Kirkby Moor
- Taff Ely

Sites using SCADA data:
- Bears Down
- Llyn Alaw
- Carno

Met Office data

The Met Office is providing forecast data extracted from the operational Mesoscale forecast. The service runs 6 hourly at the following times: 0500, 1100, 1700, 2300 GMT, and data files are delivered to ISET (via their ftp server) shortly afterwards. In addition to the January 2001-July 2002 data set already provided, this service will operate from 0000 GMT 6th January 2004 to 2300 5th January 2005, dates and times inclusive. To enable predictions to be made with longer forecast validity (more than 2 hours ahead), the full 48-hour forecast lengths will be provided by the MET office, thus providing overlapping datasets every six hours. It is also anticipated that these extended length NWPs will be released for the 2001-2002 data.

The parameters provided are as follows:
- Height above mean sea level (m)
- Surface pressure (hPa)
- Relative Humidity (%)
- 10 m U-Wind (m/s)
- 10 m V-Wind (m/s)
- Screen (1.5m) Temperature (K)

Should there be a delay in the generation of the Mesoscale forecast then one of the following actions will result:

(a) the latest available data will be used
(b) the service will be held pending until the Mesoscale forecast has been updated

The format of the files is ASCII, comma separated values (CSV) using a tabular format:

filename FFYYYYMMDDhh.dat

FF fieldsfile

YYYY	calendar year
MM	calendar month
DD	calendar day
hh	forecast validity start hour = 06|12|18|00

The data is provided for six wind farm locations. The Met Office have available data on a 1 km grid and are thus providing the data for the 4-5 grid points which are closest to each wind farm.

4.2 Adaptation of ISET's AWPT for the UK

There are two ways, sometimes used in combination, to use ANNs to predict wind power. These have been examined in the last years by several institutes. One way is to use ANN modules to describe the relationship between the power output and the predicted meteorological data (mostly wind speed and wind direction). Although it is obvious to describe this relationship with physical models it is hardly possible, because it is a very complex system. The advantage of the ANN is that they can just learn from the past no matter how complex the physical model might be. Moreover, incorporating further parameters does not require extensive modifications of the model. It turned out that it is useful to take wind data as well as other meteorological data (temperature, pressure etc.) as an input to the ANN modules.

The meteorological component of the prediction tool is based on operational weather forecasting such as provided by the meteorological services.

The other way is to predict the next step out of the run of the curve of the power from the near past. Typical daily or other periodical patterns as well as an extrapolation of the curve can be detected by the ANN and are used for a short term prediction up to a couple of hours. However, to run this kind of prediction systems the operator needs to have online access to the power production data of the wind farms.

For the case studies within the DISPOWER project National Wind Power provided SCADA data for six wind farms within the UK. Considering the run of the system online access to three farms would be possible. Meteorological forecast data for all sites were provided by the UK Met Office.

Figure 4.2 shows the schematic run of the ANN. Stored meteorological forecast data and measured power data from over 1½ years were used to train the ANN. Only half of this data were used to actually train the ANN while the other part was used to test the model. By analyzing the tests, the optimal configuration of the ANN modules and the best pre-processing of the input data were determined.

Two ANN were trained for each wind farm. One using meteorological data only according to the first way described above. The other uses power measurements in addition to implement a combination of both mentioned ways of the use of ANN for prediction.

Using meteorological data only as expected the errors are higher, because the model is not able to correct any mistakes made by the numerical weather prediction. However, the error is still in the same range than the error of the persistence model and without online measurements it is the only way to have predictions anyway.

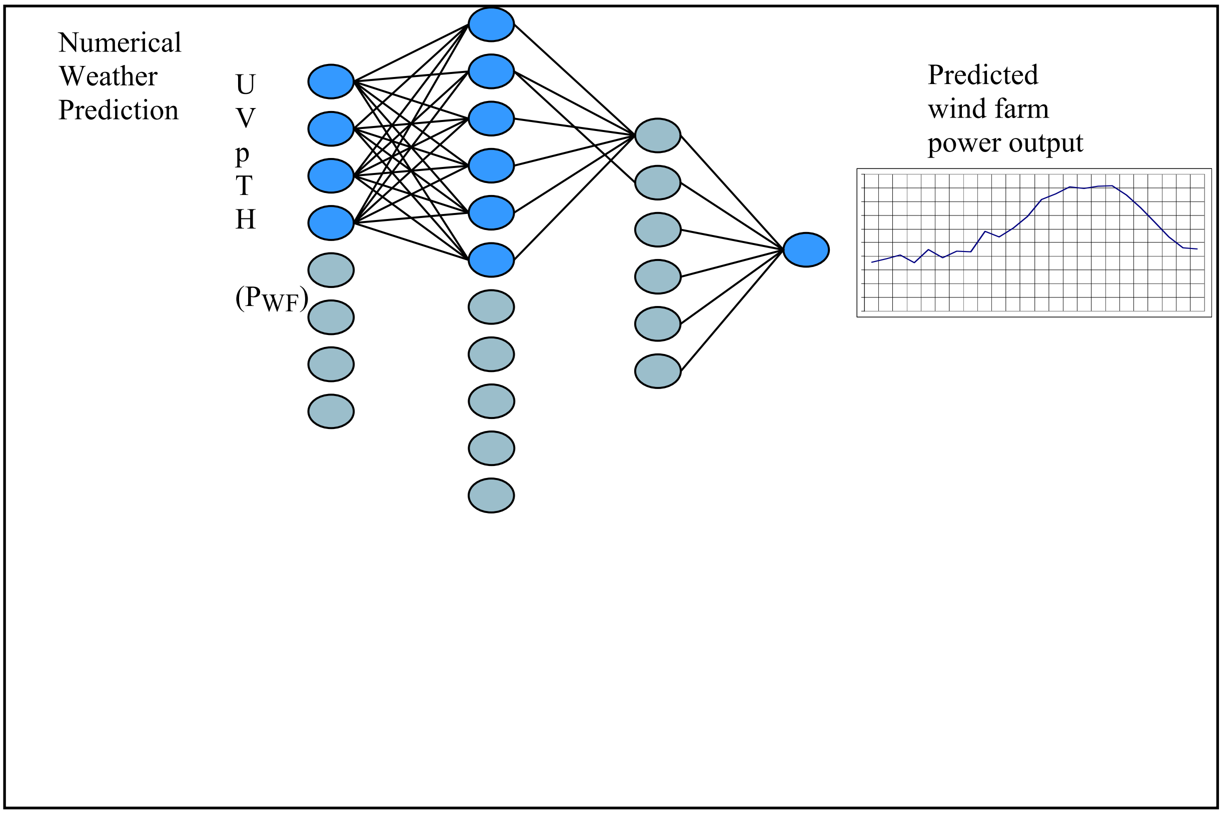


Figure 4.2: ANN Input. (vx, vy – wind speed in x and y direction; p – air pressure; T - temperature; H – humidity; C – clouds; PWF – wind farm power).

Table 4.2: Description of the inputs available and selected after the architecture optimisation process.

Inputs available	Inputs selected
Power data - SCADA	**Model 1** - Wind speed in x and y direction from 4 grid points
Meteorological forecast data from 4 surrounding grid points - Wind speed (at 10 meters) - Wind direction - Relative Humidity - Mean sea level pressure - Temperature	**Model 2** - SCADA: Measured power data from the last 4 hours - Wind speed in x and y direction from 4 grid points - Mean sea level pressure - Temperature

Table 4.3 Statistics for the two-hour forecast for all wind farms.

Name of Wind Farm	Nominal Power [MW]	NRMSE % of Nom Pow	MBE [MW]	NMAE % of Nom Pow	Correl.	Lack [MWh]	Surplus [MWh]
ANN forecast using met. data only							
Bears Down	9.6	13.5%	-0.05	9.5%	0.893	972	1083
Bryn Titli	9.9	13.9%	0.10	9.5%	0.902	2100	1699
Carno	33.6	11.0%	0.22	7.6%	0.905	5431	4595
Kirkby Moor	4.8	13.5%	-0.01	9.7%	0.904	907	942
Llyn Alaw	20.4	10.2%	-0.12	7.2%	0.941	2685	3173
Taff Ely	9	15.4%	0.17	10.5%	0.884	1983	1392
ANN forecast using met. and power data							
Bears Down	9.6	11.5%	-0.07	7.7%	0.924	869	1065
Bryn Titli	9.9	12.2%	0.07	8.6%	0.926	2255	1912
Carno	33.6	9.9%	0.11	6.8%	0.921	5818	5282
Kirkby Moor	4.8	12.8%	-0.03	9.2%	0.915	992	1150
Llyn Alaw	20.4	9.9%	-0.04	6.9%	0.944	3348	3545
Taff Ely	9	13.6%	0.06	8.9%	0.913	1821	1577

*Table 4.4: Improvement **with respect to Persistence** for the two-hour forecast for all wind farms.*

Farm	RMSE [%]	MAE [%]	Energy Lack [%]	Energy Surplus [%]
ANN forecast using NWP only				
Bears Down	1.7	-7.2	-0.4	-13.7
Bryn Titli	0.5	2.2	-8.5	12.8
Carno	2.4	2.7	-6.5	11.8
Kirkby Moor	10.0	5.0	4.7	5.3
Llyn Alaw	16.1	14.9	20.3	9.7
Taff Ely	-8.0	-2.3	-17.4	13.5
ANN forecast using NWP and power data				
Bears Down	21.9	16.4	24.2	8.6
Bryn Titli	8.9	12.2	5.2	19.3
Carno	3.4	12.4	7.8	17.0
Kirkby Moor	11.3	13.0	19.1	6.8
Llyn Alaw	16.3	19.2	21.1	17.5
Taff Ely	1.5	13.1	6.1	20.0

4.2.1 ANN forecast using meteorological data only

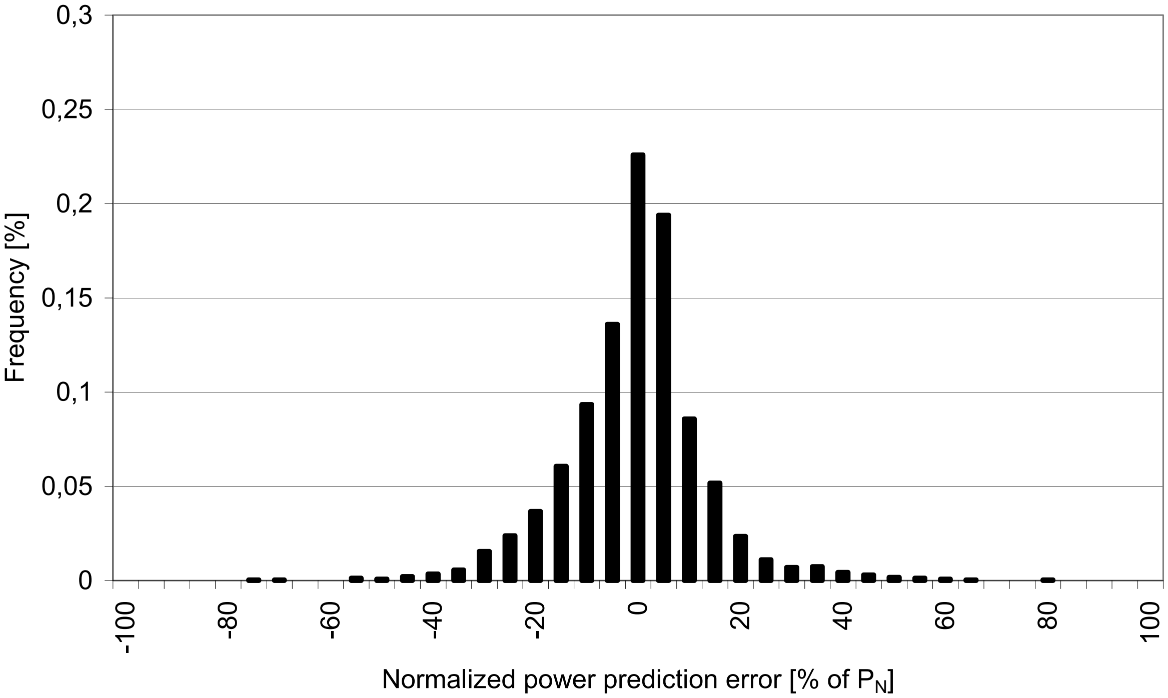


Figure 4.3: Frequency distribution of forecast errors for Bears Down.

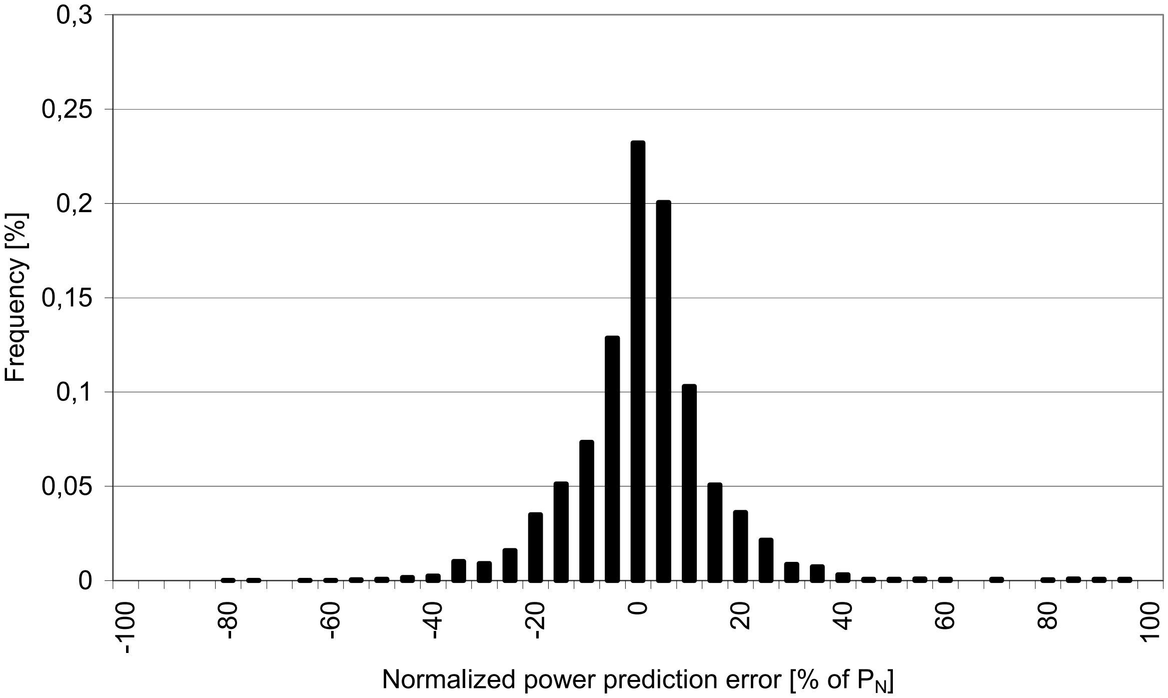


Figure 4.4: Frequency distribution of forecast errors for Bryn Titli.

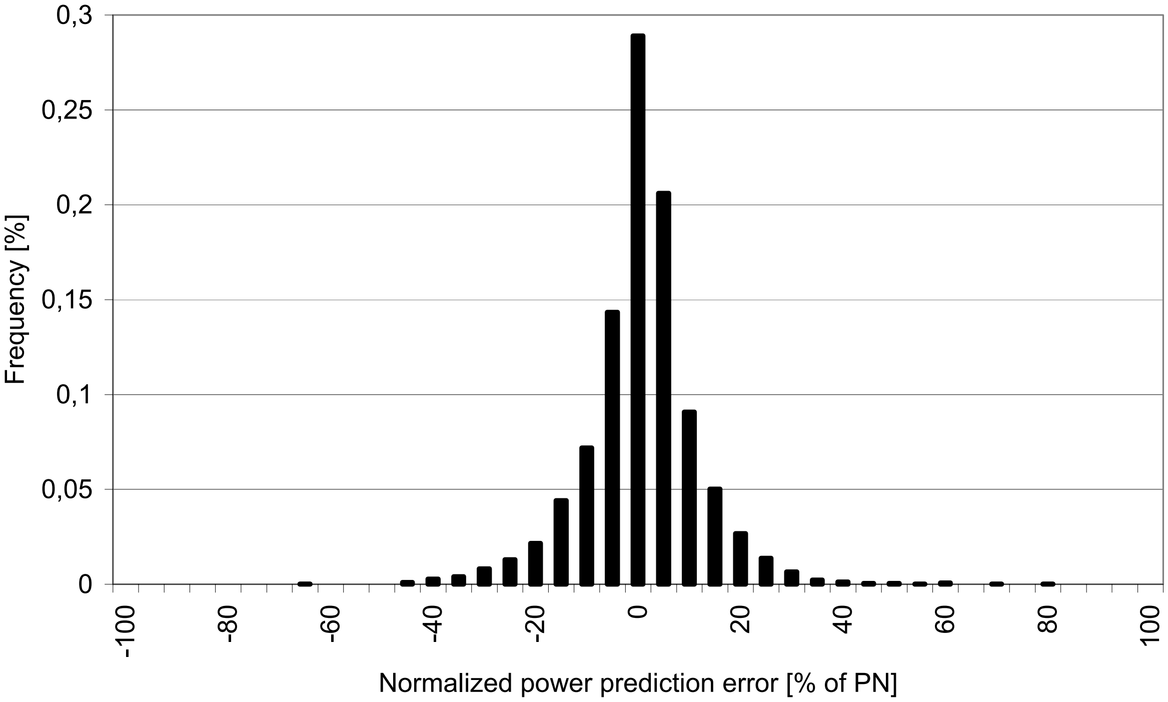


Figure 4.5: Frequency distribution of forecast errors for Carno.

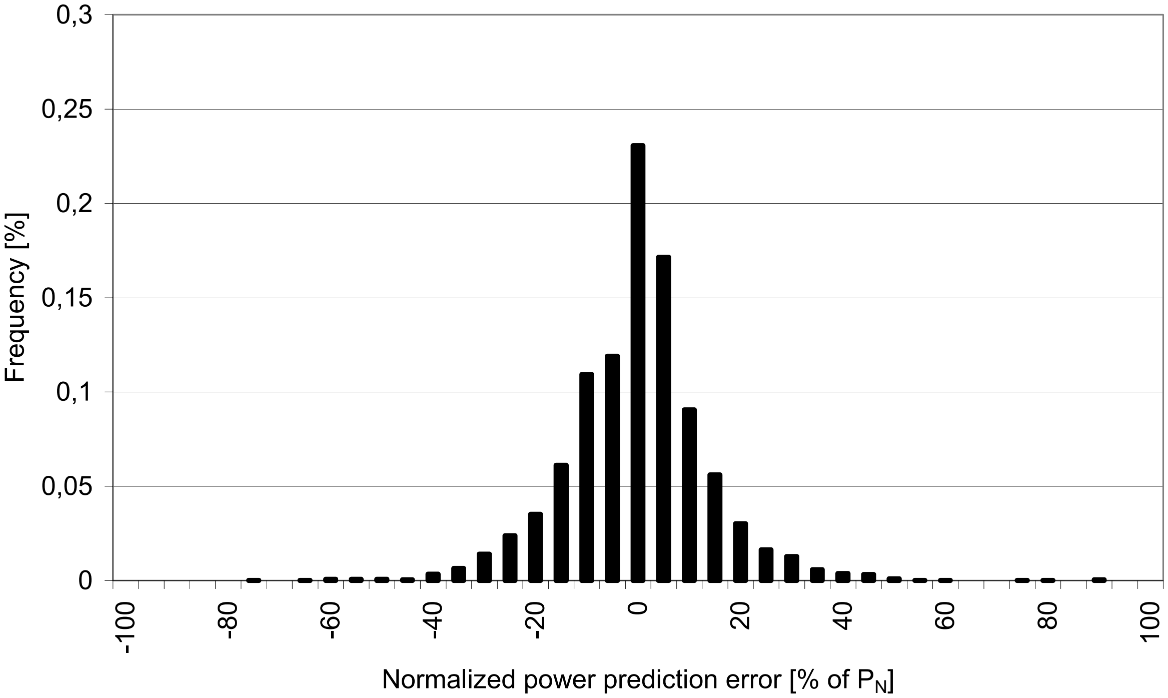


Figure 4.6: Frequency distribution of forecast errors for Kirkby Moor.

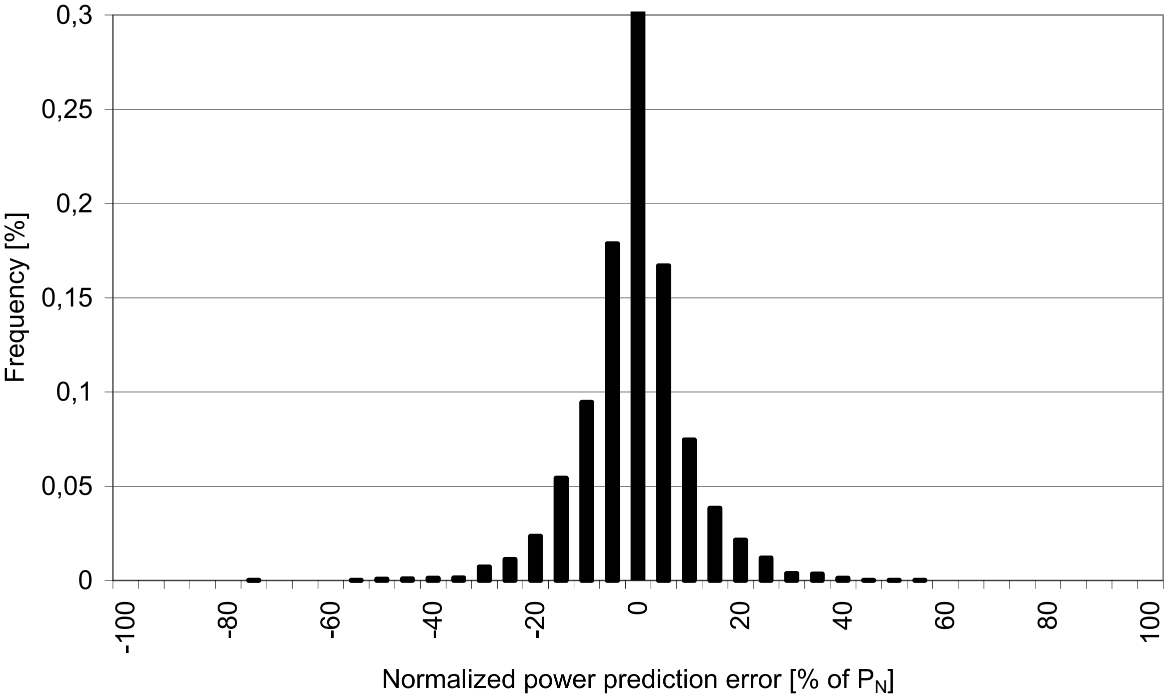


Figure 4.7: Frequency distribution of forecast errors for Llyn Alaw.

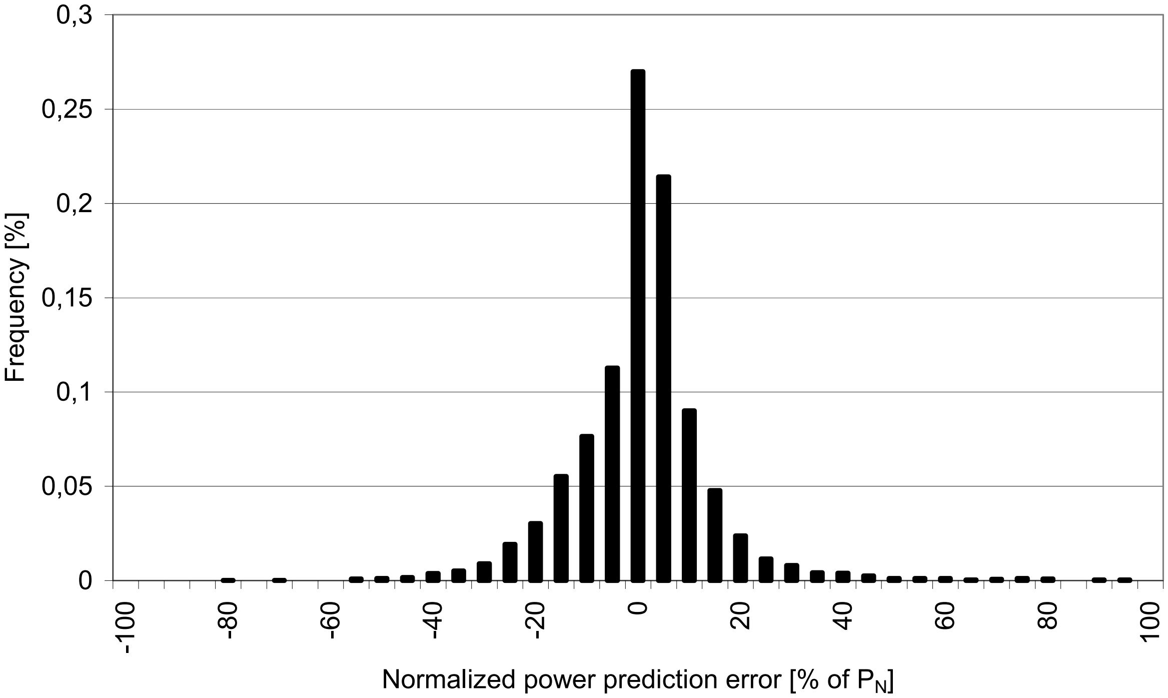


Figure 4.8: Frequency distribution of forecast errors for Taff Ely.

4.2.2 ANN forecast using meteorological and power data

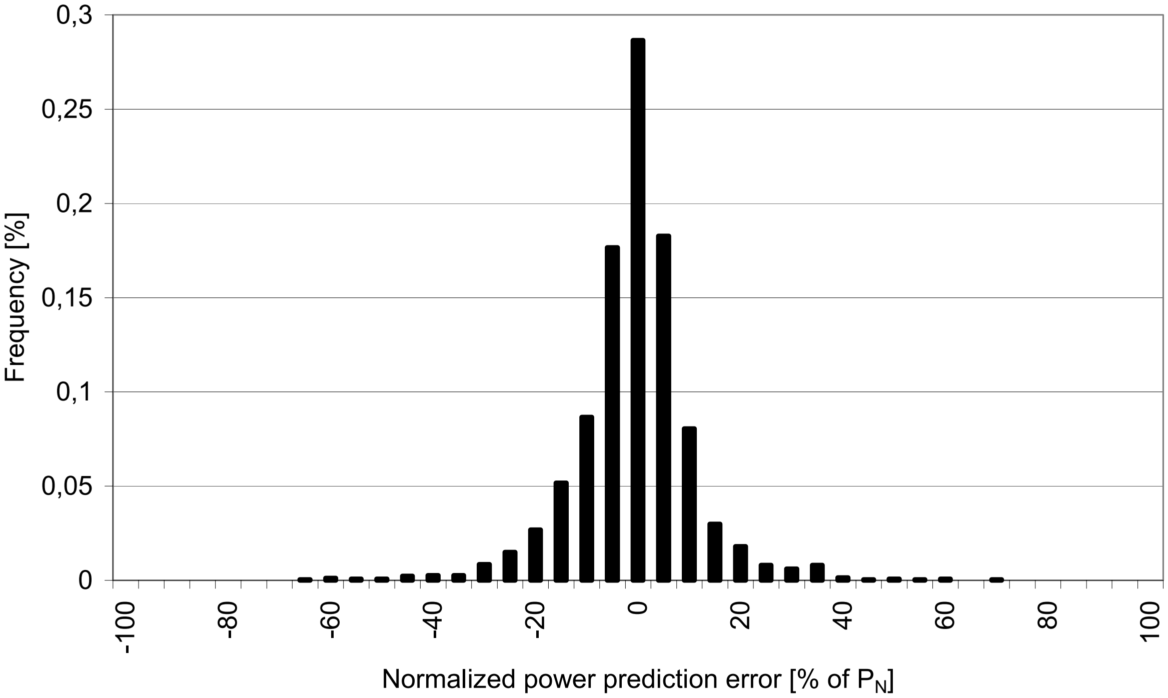


Figure 4.9: Frequency distribution of forecast errors for Bears Down.

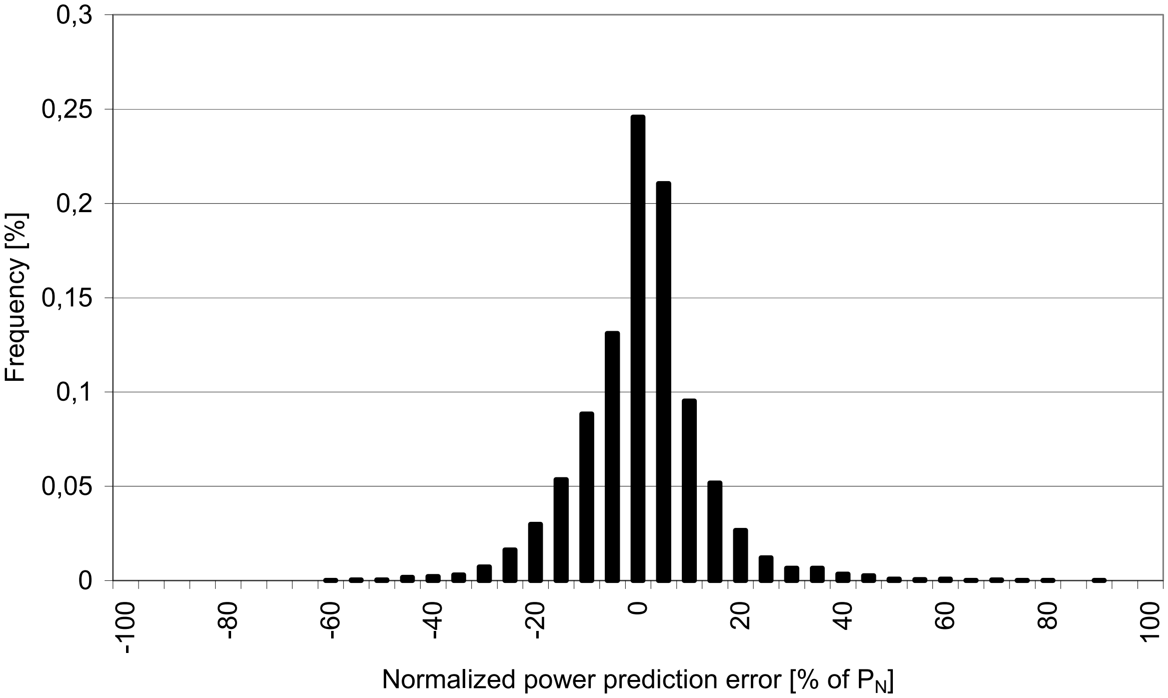


Figure 4.10: Frequency distribution of forecast errors for Bryn Titli.

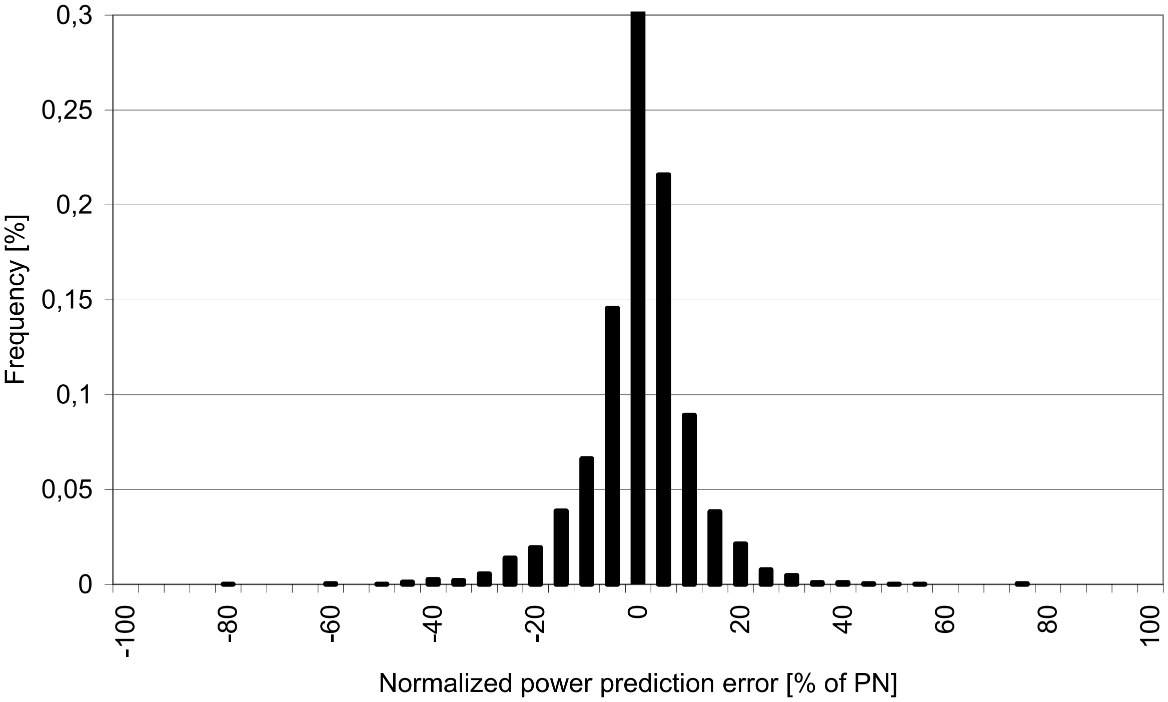


Figure 4.11: Frequency distribution of forecast errors for Carno.

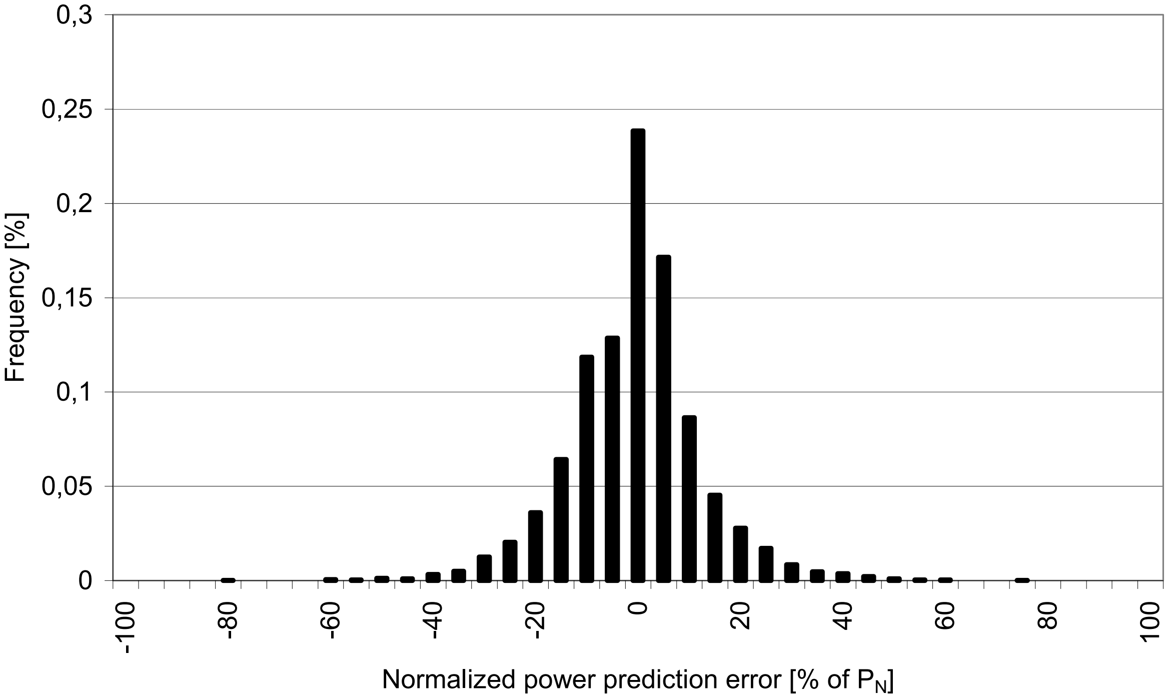


Figure 4.12: Frequency distribution of forecast errors for Kirkby Moor.

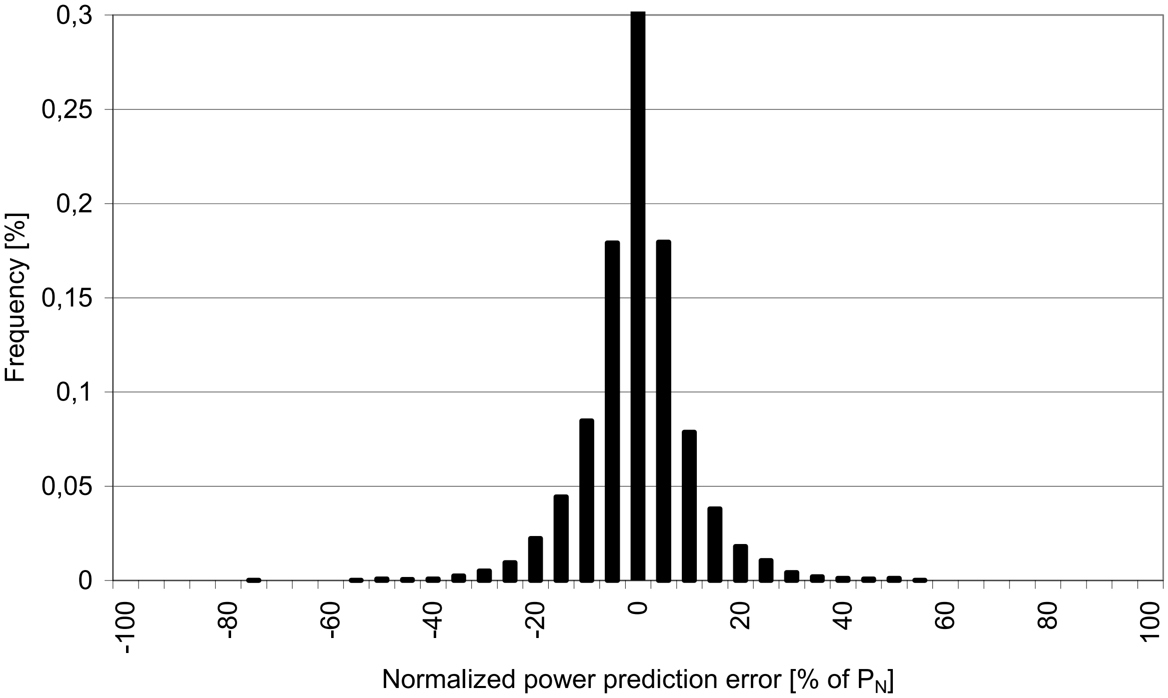


Figure 4.13: Frequency distribution of forecast errors for Llyn Alaw.

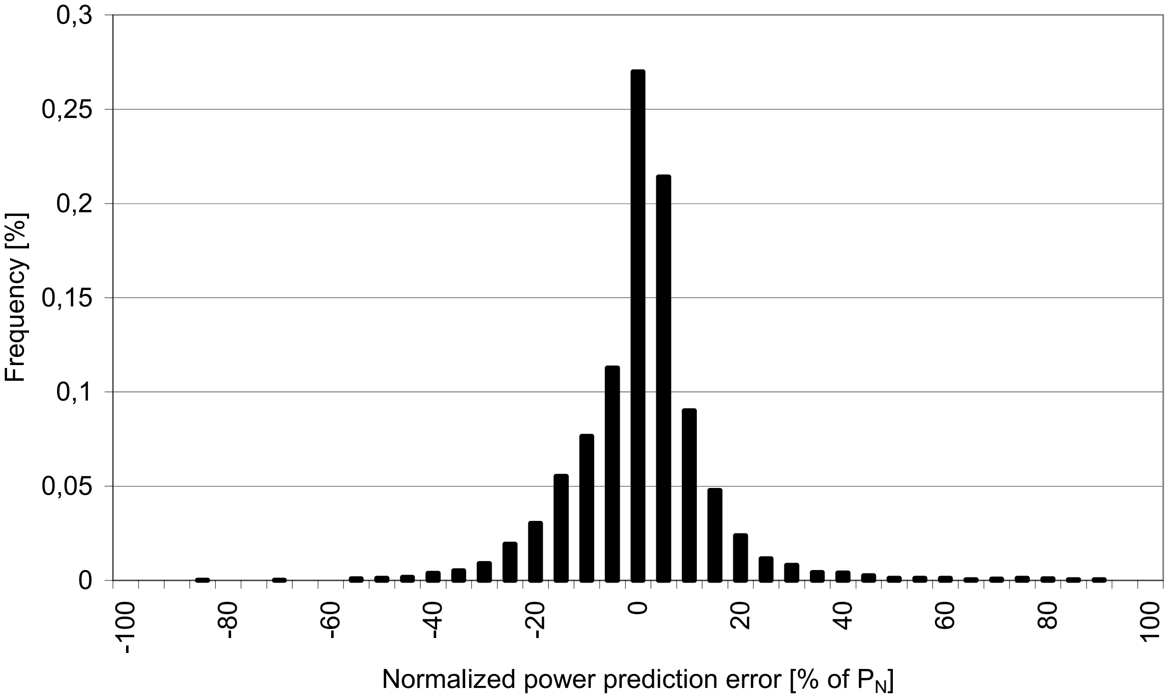


Figure 4.14: Frequency distribution of forecast errors for Taff Ely.

Table 4.5: Analysis of histograms. Probability of errors within ±10, ±20 & ±30%.

Farm	Error Range		
	[-10%, 10%]	[-20%, 20%]	[-30%, 30%]
ANN forecast using met. data only			
Bears Down	73.5	90.8	96.5
Bryn Titli	73.8	91.1	96.6
Carno	80.1	94.4	98.6
Kirkby Moor	72.1	90.4	97.1
Llyn Alaw	81.8	95.5	99.0
Taff Ely	76.3	92.0	96.8
ANN forecast using met. and power data			
Bears Down	81.3	93.9	97.7
Bryn Titli	77.1	93.3	97.6
Carno	84.0	95.8	99.0
Kirkby Moor	74.3	91.7	97.5
Llyn Alaw	83.7	96.0	98.9
Taff Ely	76.3	92.0	96.8

4.3 Adaptation of the ARMINES Wind Power Prediction System for the UK

In the following sections, results from the ARMINES Wind Power Prediction System (AWPPS) are presented for the UK case study considered in the DISPOWER project. The aim is to tune the AWPPS for predicting the output of six wind farms in UK.

4.3.1 Tuning the F-NN model for the six wind farms in the UK

The F-NN core model of AWPPS was tuned for each one of the six wind farms. For this purpose the data made available by IT Power were used. The model development process consisted of the following steps:

1. Data pre-processing. The raw data made available by IT Power were pre-processed to detect missing or erroneous values and to handle daylight saving time changes. Then, the 10-minutes power data were averaged to produce hourly values according to the protocol defined in common with ISET.

2. Separation of the data into learning and testing sets. For this purpose the proposal of ISET was followed according to which one day was used for learning and one for testing.

3. Input selection. A process, set-up by ARMINES, permits the selection of the most relevant input among the available types of data. This process was launched once for each case study.

The next paragraph presents the initially available input data, the input that was considered and finally the input that was selected. In general we did not consider in the optimization process the humidity and temperature data in order to reduce the dimensionality of the problem due to the tight project schedule for carrying out this work.

4.Model training. A number of alternative models were trained following advanced training algorithms developed for training adaptive fuzzy neural networks.

5. Model testing. The results presented below are based on the testing set as defined by ISET.

Input selection

The following Table presents the data (such as on-line production data, forecasted wind speed, etc.) that were made available for each of the case studies, the ones we decided to consider as input to the F-NN prediction model, and finally the ones that were selected after the architecture optimization process.

Table 4.6: Description of the inputs available, considered and selected after the architecture optimisation process.

Site	Inputs available	Inputs considered	Inputs selected
Bears Down	- SCADA - Wind speed (forecast at 10 meters) from 4 grid points - Wind direction (forecast at 10 meters) from 4 grid points - Relative Humidity from 4 grid points - Mean sea level pressure from 4 grid points	- SCADA - Wind speed (forecast at 10 meters) from 4 grid points - Wind direction (forecast at 10 meters) from 4 grid points	- SCADA - Wind speed (forecast at 10 meters) from 4 grid points - Wind direction (forecast at 10 meters) from 2 grid points
Bryn Titli	- SCADA - Wind speed (forecast at 10 meters) from 4 grid points - Wind direction (forecast at 10 meters) from 4 grid points - Relative Humidity from 4 grid points - Mean sea level pressure from 4 grid points	- SCADA - Wind speed (forecast at 10 meters) from 4 grid points - Wind direction (forecast at 10 meters) from 4 grid points	- SCADA - Wind speed (forecast at 10 meters) from 4 grid points - Wind direction (forecast at 10 meters) from 4 grid points
Carno	- SCADA - Wind speed (forecast at 10 meters) from 4 grid points - Wind direction (forecast at 10 meters) from 4 grid points - Relative Humidity from 4 grid points - Mean sea level pressure from 4 grid points	- SCADA - Wind speed (forecast at 10 meters) from 4 grid points - Wind direction (forecast at 10 meters) from 4 grid points	SCADA - Wind speed (forecast at 10 meters) from 4 grid points - Wind direction (forecast at 10 meters) from 2 grid points

Kirkby Moor	- SCADA - Wind speed (forecast at 10 meters) from 5 grid points - Wind direction (forecast at 10 meters) from 5 grid points - Relative Humidity from 5 grid points - Mean sea level pressure from 5 grid points	- SCADA - Wind speed (forecast at 10 meters) from 5 grid points - Wind direction (forecast at 10 meters) from 5 grid points	SCADA - Wind speed (forecast at 10 meters) from 5 grid points - Wind direction (forecast at 10 meters) from 5 grid points
Llyn Alaw	- SCADA - Wind speed (forecast at 10 meters) from 5 grid points - Wind direction (forecast at 10 meters) from 5 grid points - Relative Humidity from 5 grid points - Mean sea level pressure from 5 grid points	- SCADA - Wind speed (forecast at 10 meters) from 5 grid points - Wind direction (forecast at 10 meters) from 5 grid points	SCADA - Wind speed (forecast at 10 meters) from 5 grid points - Wind direction (forecast at 10 meters) from 5 grid points
Taff Ely	- SCADA - Wind speed (forecast at 10 meters) from 5 grid points - Wind direction (forecast at 10 meters) from 5 grid points - Relative Humidity from 5 grid points - Mean sea level pressure from 5 grid points	- SCADA - Wind speed (forecast at 10 meters) from 5 grid points - Wind direction (forecast at 10 meters) from 5 grid points	SCADA - Wind speed (forecast at 10 meters) from 4 grid points - Wind direction (forecast at 10 meters) from 3 grid points

4.3.2 Results

The following table summarises the results obtained for each wind farm for the tuned F-NN model as well as for Persistence. The evaluation criteria were defined in common with ISET. The values are normalised using the wind farm Nominal power. The NRMSE is between 9.5-12.9% according to the wind farm for the 2-step ahead forecasts. As expected the NMAE is lower and between 6.29-8.69%. Significant improvement w.r.t. Persistence is obtained for all criteria which rises up to 21.5% for NRMSE and 18.5% for NMAE.

The histograms of the prediction errors for 2 hours ahead for all wind farms are given in the following Figures. Table 4.9 gives the probabilities that the prediction error lie between ±10, ±20 & ±30%. In the first case and depending on the wind farm, 75.3 to 85% of errors are between ±10%. Also 92.3 to 96.3% (depending on the wind farm) of errors are between ±20%. Finally, 97.6 to 99% of errors are between ±30%.

Table 4.7: Statistics for the two-hour forecast of all wind farms.

Name of Wind Farm	Nominal Power [MW]	NRMSE % of Nom Pow	MBE [MW]	NMAE % of Nom Pow	Correl.	Lack [MWh]	Surplus [MWh]
F-NN Forecast							

Bears Down	9.6	11.3	-0.023	7.65	0.925	768	772
Bryn Titli	9.9	12	0.007	8.69	0.924	1493	1497
Carno	33.6	9.3	0.042	5.95	0.929	4684	4400
Kirkby Moor	4.8	12.1	-0.011	8.26	0.923	784	848
Llyn Alaw	20.4	9.5	-0.018	6.29	0.948	2871	3014
Taff Ely	9	12.9	-0.044	8.15	0.915	1407	1446
Persistence							
Bears Down	9.6	14.3	-0.021	9.39	0.884	968	923
Bryn Titli	9.9	15.2	-0.005	10.59	0.882	1833	1813
Carno	33.6	11.2	-0.020	6.81	0.900	5253	5160
Kirkby Moor	4.8	15	0.004	9.75	0.887	954	972
Llyn Alaw	20.4	12.1	0.012	7.48	0.919	3470	3529
Taff Ely	9	15.5	-0.034	9.20	0.884	1677	1543

Table 4.8: Improvement with respect to Persistence for the two-hour forecast of all wind farms.

Farm	RMSE %	MAE %	Energy Lack %	Energy Surplus %
Bears Down	20.98	18.53	20.66	16.36
Bryn Titli	21.05	17.94	18.54	17.42
Carno	16.96	12.63	10.83	14.73
Kirkby Moor	19.33	15.28	17.81	12.75
Llyn Alaw	21.49	15.90	17.26	14.59
Taff Ely	16.77	11.41	16.10	6.28

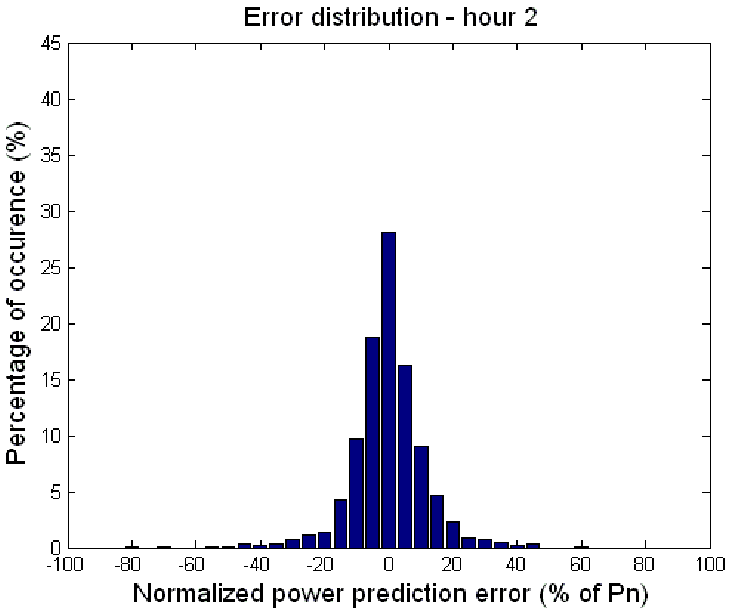


Figure 4.15: Frequency distribution of forecast errors for Bears Down

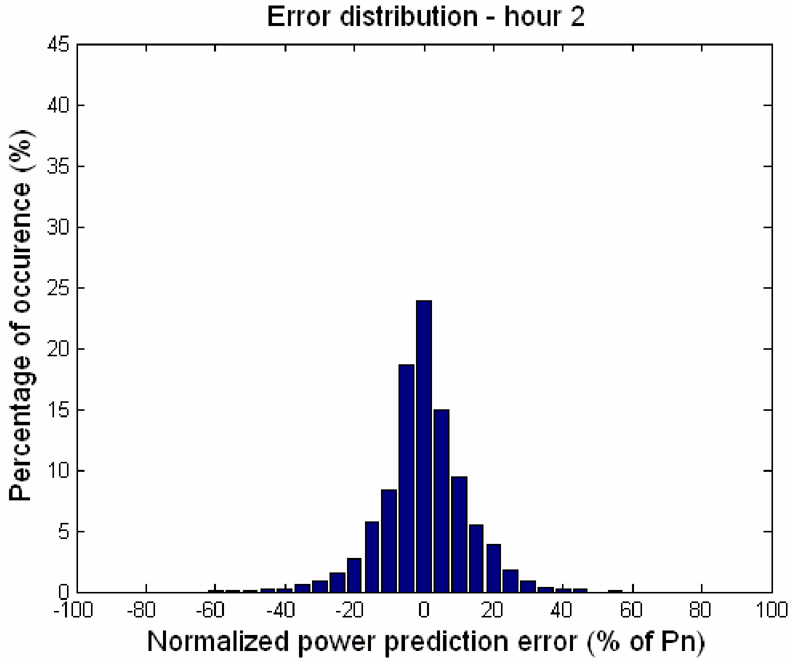


Figure 4.16: Frequency distribution of forecast errors for Bryn Titli

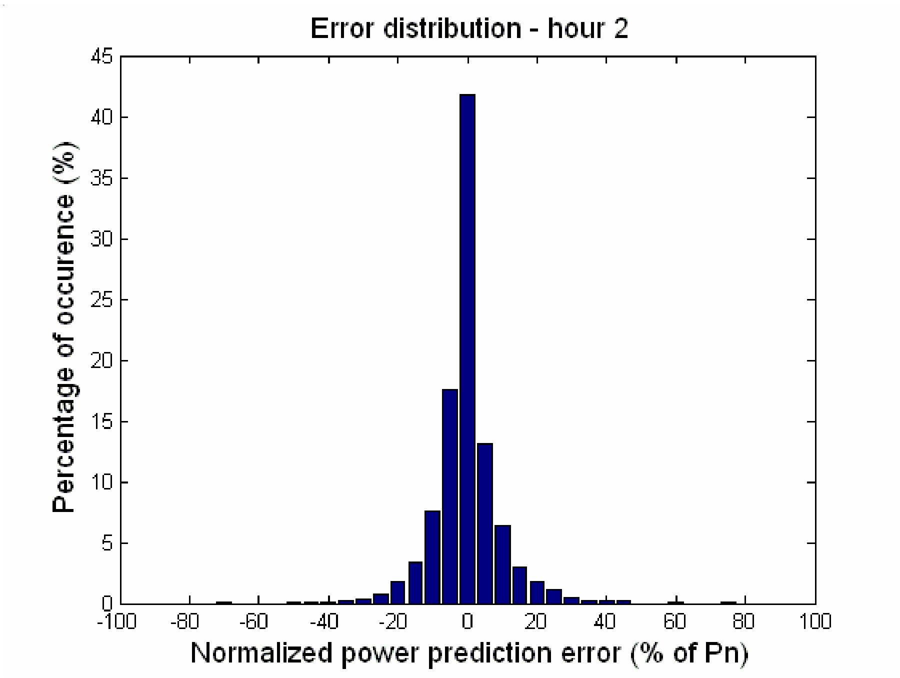


Figure 4.17: Frequency distribution of forecast errors for Carno

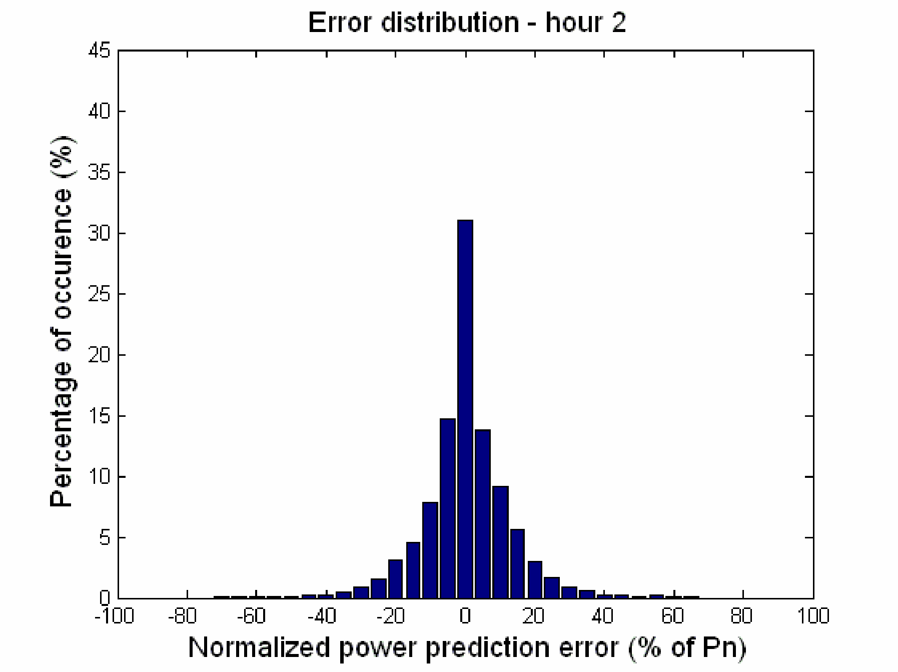


Figure 4.18: Frequency distribution of forecast errors for Kirkby Moor

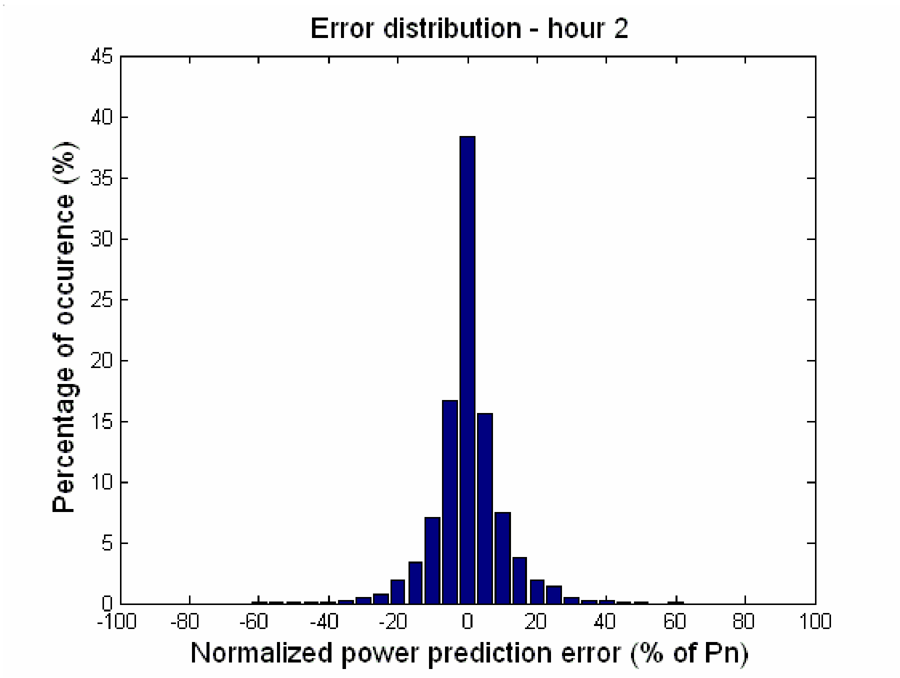


Figure 4.19: Frequency distribution of forecast errors for Llyn Alaw

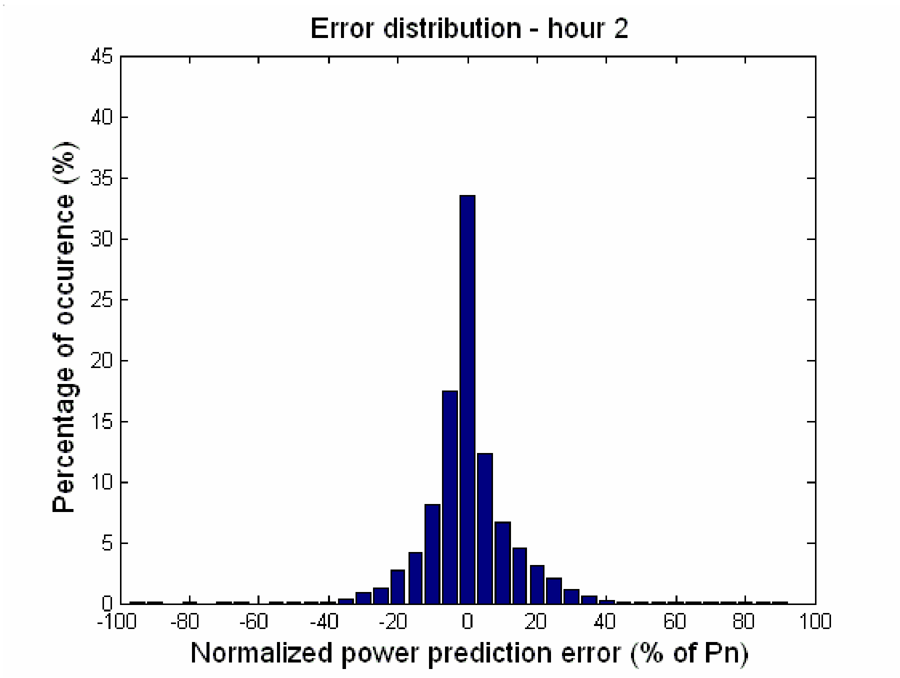


Figure 4.20: Frequency distribution of forecast errors for Taff Ely

Table 4.9: Analysis of histograms. Probability of errors within ±10, ±20 & ±30%.

	Error Range		
	[-10%, 10%]	[-20%, 20%]	[-30%, 30%]
Bears Down	81.8	94.4	97.8
Bryn Titli	75.3	93.0	98.0
Carno	86.3	96.3	99.0
Kirkby Moor	76.6	92.7	97.6
Llyn Alaw	85.0	95.9	99.0
Taff Ely	77.9	92.3	97.6

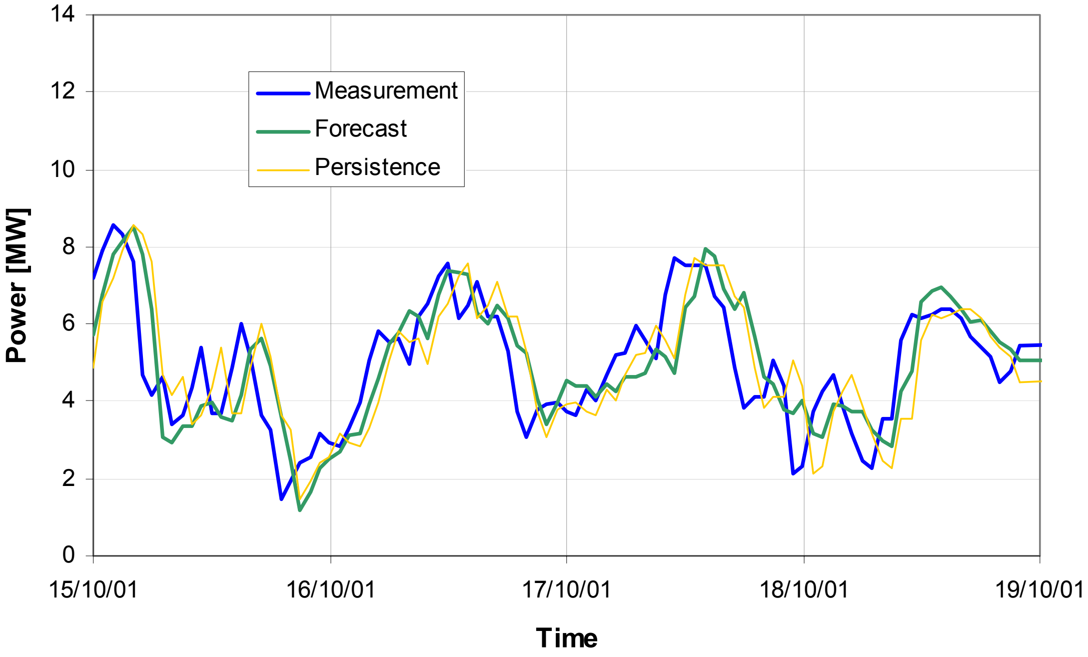


Figure 4.21: Measured and predicted power output for wind farm Bears down using the AWPPS model (period 15/10/2001-18/10/2001)

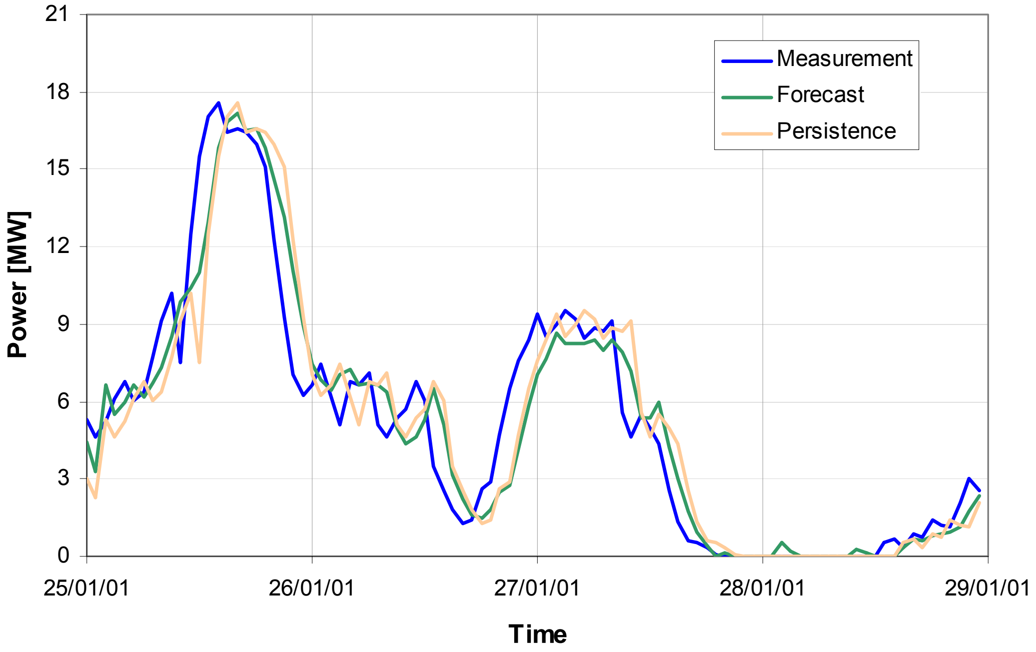


Figure 4.22: Measured and predicted power output for wind farm Bears down using the AWPPS model (Period 25/01/2001 – 28/01/2001).

4.4 Conclusions

This report presents evaluation results from ISET's AWPT and ARMINES Wind Power Prediction System (AWPPS). Both systems are able to provide end-users with wind power forecasts for horizons up to two-days ahead (or more depending on the length of NWPs) by considering as input both on-line production data and numerical weather predictions. Here the aim, as set by IT Power, was to produce predictions for 2 hours ahead.

The cores of the models are based on artificial neural networks (ISET) and adaptive fuzzy neural networks (Armines). They are integrated in the Wind Power Management System and in the More-Care Energy Management System respectively. Here, they have been used as a stand-alone system and adapted for the UK case.

The models have been trained using the data provided by IT Power for 6 wind farms in UK. The input data and configuration has been optimised for each case using the cross-validation approach. The evaluation results presented in this report compare the performance of the models to the ones of Persistence, in terms of MAE, RMSE and energy lack and energy surplus on a global basis. In addition to that, distributions of the prediction errors are shown in order to give a clear view of the forecast uncertainty.

Globally, the results in this report are satisfactory for the problem of single wind farm forecasting and comparable to the ones found in the literature. For instance, it can be seen that the RMSE is lower than 12.9% of the installed capacity for all the case studies. Moreover, the improvement with reference to persistence raises up to 21.9% for the RMSE criterion and to 18.5% for the MAE criterion depending on the case study. Regarding the error distributions, one can notice that they are quite sharp and the number of outliers is negligible. These results can be considered as base-line ones. In case that an on-line installation is foreseen, additional optimizations are performed for an optimal on-line performance.

5 References

BAILEY B., BROWER M., ZACK J., Applications and Validations of the Mesomap Wind Mapping System in Different Climatic Regimes, Windpower 2001, Washington D.C., June 2001

BAILEY B., BROWER M., ZACK J., Wind Forecast: Development and Applications of a Mesoscale Model, 33 Meeting of Experts, Technical Report from the International Energy Agency, R&D Wind, Ed. S.-E. Thor, FFA, Sweden, 93-116, July (2000).

BEYER H. G., HEINEMANN D., MELLINGHOF H., MÖNNICH K., WALDL H.-P., Forecast of Regional Power Output of Wind Turbines, 1999 European Wind Energy Conference and Exhibition, Nice, France, March 1999.

DUTTON A.G., KARINIOTAKIS G., HALLIDAY J.A., NOGARET E.,“ Load and Wind Power Forecasting Methods for the Optimal Management of Isolated Power Systems with High Wind Penetration”,Wind Engineering, Vol. 23, No 2, 2000.

EICHHORN J. et.al., A Three-Dimensional Viscous Topography Mesoscale Model, Contributions to Atmospheric Physics, Vol.70,No.4, November 1997.

ENSSLIN C., ERNST B., ROHRIG K., SCHLÖGL F. (2003), Online monitoring and prediction of wind power in German transmission system operation centers, European Wind Power Conference and Exhibition, Madrid, Spain, 2003

ENßLIN C., HOPPE-KILPPER M., KLEINKAUF W., ROHRIG K., Online Monitoring of 1700 MW Wind Capacity in a Utility Supply Area, European Wind Energy Conference 1999

EUROPEAN WIND ENERGY ASSOCIATION, Press Release 24, January 2000

FOCKEN U., LANGE M., WALDL H.-P., Previento - A Wind Power Prediction System with an Innovative Upscaling Algorithm, 2001 European Wind Energy Conference and Exhibition, Bella Center, Copenhagen, Denmark, 2-6 July 2001.

HATZIARGYRIOU N., CONTAXIS G., KARINIOTAKIS G., ET AL., “More Care-Advice for Secure Operation of Isolated Power Systems with Increased Renewable Energy Penetration & Storage”, Proceedings of the 2001 European Wind Energy Conference EWEC'01, Copenhagen, Denmark, 2-6 July, 2001.

HATZIARGYRIOU N., KARINIOTAKIS G., ET AL, The "CARE" System Overview: Advanced Control Advice for Power Systems with Large-scale Integration of Renewable Energy Sources”, Wind Engineering, Vol. 23, No 2, 2000.

HATZIARGYRIOU N., KARINIOTAKIS G., ET AL., “Preliminary Results From the More Advanced Control Advice Project for Secure Operation of Isolated Power Systems with Increased Renewable Energy Penetration and Storage.”, Procd. of the 2001 IEEE Porto Power Tech Conference, Porto, Portugal, 10-13 September, 2001.

HOLTTINEN H., NIELSEN T.S., GIEBEL G. (2002), Wind energy in the liberalised market – forecast errors in a day ahead market compared to a more flexible market mechanism, 2nd

International Symposium on Distributed Generation: Power System and Market Aspects, 2.-4. 10. 2002, Stockholm

INSTITUT FÜR SOLARE ENERGIEVERSORGUNGS-TECHNIK, Wind Energy Report Germany 2002, September 2002.

Integration of Wind Energy in the electrical network of EU member states – IRENE, EC funded project, ALTENER XVII/4.1030/Z/99-115

KARINIOTAKIS G. N., "Contribution au développement d'un système de contrôle avancé pour les systèmes éolien-diesel autonomes", Thèse de doctorat européen, Ecole des Mines de Paris, Spécialité énergétique, Décembre 1996.

KARINIOTAKIS G. NOGARET E., STAVRAKAKIS G., "Advanced short-term forecasting of wind power production", Procd. of the 1997 European Wind Energy Conference EWEC'97, Dublin, Ireland, 1997, pp. 751-754.

KARINIOTAKIS G., M. MATOS, V. MIRANDA, "Assessment of the benefits from advanced load & wind power forecasting in autonomous power systems", Proceedings of the 1999 European Wind Energy Conference EWEC'99, Nice, France, 1-5 March, 1999.

KARINIOTAKIS G., MAYER D. “An Advanced On-Line Wind Resource Prediction System for the Optimal Management of Wind Parks.”, Accepted for presentation at the IEEE/IEE MedPower2002 Conference, Athens, Greece, November 2002.

KARINIOTAKIS G., NOGARET E., DUTTON A., HALLIDAY J. ANDROUTSOS A., "Evaluation of advanced wind power and load forecasting methods for the optimal management of isolated power systems.”

KARINIOTAKIS G., NOGARET E., STAVRAKAKIS G., “A fuzzy logic and a neural network based wind power forecasting model”, Procd. of the 1996 European Union Wind Energy Conference, EUWEC'96, Göteborg, Sweden, 20-24 May, 1996, pp. 596-599.

KARINIOTAKIS G., STAVRAKAKIS G.S. NOGARET E.F., “Wind power forecasting using advanced neural network models”, IEEE Transactions on Energy Conversion, Vol. 11, No. 4, December 1996, pp. 762-767. (96 SM 552-0 EC), Presented at the 1996 IEEE/PES Summer Meeting, July 28-Aug. 1, 1996, Denver, Colorado.

LANDBERG L., JOENSEN A., GIEBEL G., MADSEN, H., NIELSEN, T.S., Short Term prediction towards the 21st Century. In Wind Forecasting Techniques, 33 Meeting of Experts, Technical Report from the International Energy Agency, R&D Wind, Ed. S.-E. Thor, FFA, Sweden, 77-85, July (2000).

LANDBERG L., Prediktor – an On-Line Prediction System, Wind Power for the 21st Century, Special Topic Conference and Exhibition, Convention Centre, Kassel, Germany, 25-27 September 2000.

LANDBERG, L., JOENSEN, A., GIEBEL, G., MADSEN, H., NIELSEN, T.S., Zephyr, The Short-Term Prediction Models, Wind Power for the 21st Century, Special Topic Conference and Exhibition, Convention Centre, Kassel, Germany, 25-27 September 2000.

LEMNOS PROJECT (JOULE-II Jou2-CT92-0053) "Development and implementation of an advanced control system for the optimal operation and management of medium-size power systems with a large penetration from renewable energy sources".

MOEHRLEN C. AND JESS U. JOERGENSEN, “Report on the developments of HIRLAM as wind energy prediction system“, University College, Cork, Irland, August 2001

MOEHRLEN C., JØRGENSEN J. U., SATTLER K., MCKEOGH E. J., On the accuracy of land cover data in NWP forecasts for high resolution wind energy prediction, 2001 European Wind Energy Conference and Exhibition, Bella Center, Copenhagen, Denmark, 2-6 July 2001.

MOEHRLEN C., On the Benefits of and Approaches to Wind Energy Forecasting, invited Speeker at the Irish Wind Energy Association Annual Conference "Towards 500MW", Ennis, 25th May 2001.

NIELSEN T.S., MADSEN H., TOFTING T., WPPT, A Tool for On-Line Wind Power Prediction. In Wind Forecasting Techniques, 33 Meeting of Experts, Technical Report from the International Energy Agency, R&D Wind, Ed. S.-E. Thor, FFA, Sweden, 93-116, July (2000).

NOGARET E., STAVRAKAKIS G. S., KARINIOTAKIS G. N., "An advanced control system for the optimal operation and management of medium size power systems with a large penetration from renewable power sources", Renewable Energy, Vol. 12, No. 2, 1997, pp. 137-149.

PROCEEDINGS OF THE 1999 EUROPEAN WIND ENERGY CONFERENCE EWEC'99, Nice, France, 1-5 March, 1999.

PROGRESS REPORT FOR DISPOWER, Reporting Period from 2002-01-01 to 2002-12-31, Project founded by the European Commission und the 5th (EC) RTD Framework Programme (1998-2002) within the thematic programme “Energy, Environment and Sustainable Development”, Contract No. ENK5-CT-2001-00522

RIES R., HEIL O., Einsatz anspruchsvoller Verfahren zur flächendeckenden Windpotentialanalyse im Binnenland, WMEP Jahresauswertung 1996, ISET 1997.

SÁNCHEZ I. et al, „SIPREÓLICO - A Wind power prediction system based on flexible combination of dynamic models. Application to the Spanish power system”, First Joint Action Symposium on Wind Forecasting Techniques, International Energy Agency, R&D Wind, Ed. S.-E. Thor, FFA, Sweden, Dec 2002.

TANDE J. O. G., LANDBERG L., A 10 Sec. Forecast of Wind Turbine Output with Neural Networks, European Wind Energy Conference 1993

6 Links

DMI, HIRLAM
http://www.dmi.dk/eng/f+u/index.html
http://www.knmi.nl/hirlam/

Risø, Prediktor, Zephyr
http://www.risoe.dk/
http://www.prediktor.dk/

UCC, HIRPOM
http://www.ucc.ie/ucc/depts/civil/SERG/corinna.html
http://www.ucc.ie/ucc/depts/civil/SERG/HIRPOMreport.html

ISET
http://www.iset.uni-kassel.de

Uni Oldenburg, Previento
http://www.physik.uni-oldenburg.de/ehf/WIND/download/download.html
http://www.previento.de/

Deutscher Wetterdienst
http://www.dwd.de/

Project MORE-CARE
http://www-cenerg.cma.fr/more-care

Project ANEMOS
http://anemos.cma.fr

HONEYMOON-Project
http://www.honeymoon-windpower.net/

Electricity market in UK
http://www.ofgem.gov.uk

7 Projects with research on wind power forecasting

2002 –2006	ANEMOS (NNE5-2001-00857) Development of a next generation wind resource forecasting system for the large-scale integration of onshore and offshore wind farms.
1999-2003	More-Care (ERK5-CT1999-00019) “More Advanced Control Advice for Secure Operation of Isolated Power Systems With Increased Renewable Energy Penetration and Storage”.
1997-1999	CARE (JOULE-III JOR-CT96-0119) "Advanced Control Device for Power Systems with Large Scale Integration of Renewable Energy Sources"
1993-1996	LEMNOS (JOULE-II Jou2-CT92-0053) "Development and implementation of an advanced control system for the optimal operation and management of medium-size power systems with a large penetration from renewable energy sources".

8 Abbreviations

ACE	Area Control Error
ADEME	Agence pour le Développement et la Maîtrise de l’énergie [Agency for the Development and Control of Energy]
ANN	Artificial Neural Networks
AWPPS	Armines Wind Power Prediction System
AWPT	ISETs Advanced Wind Power Prediction Tool
CORR	Correlation
CRE	Commission de Régulation de l’Electricité [Commission for Regulation of Electricity]
ENL	Energy Lack
ENS	Energy Surplus
F-NN	Fuzzy-Neural Network
MAE	Mean Absolute Error
MBE	Mean Bias Error
NETA	New Electricity Trading Arrangement
NMAE	Normalised Mean Absolute Error
NRMSE	Normalised RMSE
NWP	Numerical Weather Predictions
RES-E	Electricity produced from Renewable Energy Sources
RMSE	Root Mean Square Error
RTE	Réseau de Transport d’Electricité [Electricity Transport Network]
SCADA	Supervisory Control and Data Acquisition
WPMS	Wind Power Management System