Potential benefits of wind forecasting and the application of more-care in Ireland

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ABSTRACT: The Irish Electricity System and its future developments with regard to the integration of wind energy is described. The importance of an accurate wind forecasting tool and the development of the More-Care wind modules for use by the Transmission System Operator (TSO) in Ireland is outlined. An accurate tool for wind forecasting is anticipated to greatly help in permitting greater penetration of renewable energy sources in our island system.

Keywords: Wind Forecasting, More-Care, TSO, Hirlam.

I. INTRODUCTION

Presently there is 137 MW of wind generation installed in the Republic of Ireland which amounts to around 3% of system capacity. In May 2002 contracts were awarded, under the fifth Alternative Energy Requirement (AER) competition, to 354 MW of wind projects with planning permission by the Irish government [1].

This was a step in the right direction towards the target of 500 MW of renewable capacity by 2005 in Ireland [2]. If Ireland is to meet the E.U. target of 13.2 % of total energy from renewables by 2010, wind farm development will have to move at a more accelerated pace than up to now [3].

The Transmission System Operator (TSO) requires an accurate and reliable wind power forecasting system if the large-scale integration of wind energy is to be successful.

This project produces forecasts for eleven wind farms with installed capacity of 69.49 MW and uses HIRLAM weather forecasts provided by Met Éireann as input.

This paper:

1. Describes the difficulties posed by increased levels of wind penetration for the TSO.
2. Introduces the two More-Care wind forecasting modules for use in the National Control Centre in Dublin and presents some preliminary results.

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II. THE IRISH ELECTRICTY SYSTEM

Northern Ireland and The Republic of Ireland form one synchronous system at 50 Hz. With regards to the Republic of Ireland, 93% of the energy is from thermal plant, 4 % from hydro and 3 % from wind and other renewables. The Irish electricity transmission network consists of over 5,800 km of lines and cables at 400 kV, 220 kV and 110 kV and is operated from the National Control Centre in Dublin by ESB National Grid (TSO license).

Figure 1: The Irish Transmission System

The nominal installed capacity in the Republic of Ireland is currently 5.5 GW. Since the opening of the market in February 2000, 3 thermal Independent Power Producers (IPP) totalling 862 MW have been connected to the transmission system. The System peak in 2001 occurred in December and was 4091 MW. 24.2 TWhr of energy was generated that year. In 2000 the peak of 3844 MW was also in December and 22.9 TWhr was the annual system energy. The layout of the Irish Transmission System in the Republic and the North can be seen from **Figure 1**.

The level of interconnection between the South and North systems has increased with the upgrading of the main north-south interconnector between the ESB 220 kV system and the NIE 275 kV system and the upgrading of two (formerly standby) interconnectors at 110 kV through the use of phase shifting transformers. In addition the new 500 MW HVDC link between NIE and Scotland has been in commercial operation since January 2002.

III. ANTICIPATED PROBLEMS FOR THE TSO

The main obligation of a Transmission System Operator (TSO) is to provide an efficient, reliable and secure transmission system, whilst ensuring efficient system co-ordination and real-time electricity supply.

The present level of wind generation is discernible to the System Operator and impacts on the scheduling and dispatch of conventional marginal plant. Without an accurate forecast the Operator has to be conservative and assume there is little or no wind. Under-exploiting renewables in this way can increase the already large costs of electricity in islands. The trend is towards larger wind farms with the likelihood of large offshore wind farms – predominately along the East Coast where it is shallow.

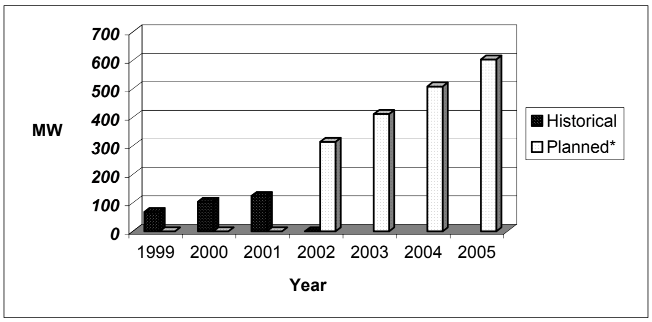

Figure 2: Planned Growth of Wind Energy [1].

As wind farms increase in size, it is extremely important for the System Operator to receive on-line data for each wind farm:

• wind speed	• kV
• wind direction	• Availability
• temperature	• plant status
• pressure	• potential output
• MW	• Setpoint
• MVAR	

This online data – especially the MW signal – is very useful for Operators as another measure of accuracy of the forecast.

Due to the nature of the Irish System in so far as it is a small island system and wind generators displace conventional generators, it is necessary to also consider effects such as:

- Frequency regulation
- Active Power Control (dispatchability)
- Reactive Power Control
- Reserve
- Marginal plant
- Fault ride through capability

In addition to these, there is also the problem of this volatile power source locating in areas where the Grid is weak.

IV. TSO REQUIREMENTS

In order to fully benefit from a large-scale integration of wind power on the Irish power system it would be a great advantage to know as far as possible in advance, with a given amount of certainty, the wind power production. This paper deals with forecasting 48 hours in advance but an accurate 7-day forecast or even longer would be very beneficial to the TSO in operating the electricity system. It is very important that the forecast is both accurate and reliable.

The requirements of the transmission system operator for a wind power forecasting system can be summarised as follows:

a) Forecasts should be available for individual windfarms and groups of wind farms.
b) forecasts should be wind power output, in MW, rather than wind speed,
c) hourly forecasts extending out to a forecast horizon of at least 48 hours,
d) an accurate forecast with an associated confidence level (dispatchers would tend to be more conservative when dealing with larger forecast uncertainties),
e) a reliable forecast of likely changes in wind power production and
f) a better understanding of the meteorological conditions which would lead to the forecasts being poor
g) Use of historical data to improve accuracy of forecast over time - the method for doing this needs to be built into the program

V. MORE-CARE WIND MODULES

The objective of the More-Care project has been to develop an advanced Energy Management System (EMS) to assist the operators of a medium or a large isolated power system

For the case of Ireland, More-Care has been configured to operate as a stand-alone wind forecasting platform for the prediction of the output of eleven wind farms.

As part of the More-Care platform two wind modules were developed for Ireland by:

1. Ecole des Mines de Paris / Armines
2. Rutherford Appleton Lab (RAL)

Both modules are developed in a generic way so as to be able to handle future installations of wind farms. For this reason, the modules communicate with a relational database that handles all static parameters as well as input and output data.

A. Wind Power Forecasting MODULE 1

ARMINES has developed a wind power forecasting module integrating short and long-term models [4].

Short-term models: Such models predict wind power based only on past measured data available from the SCADA system. The aim is to capture temporal correlations in the data and use them to predict the future. Adaptive fuzzy neural networks (F-NN) were found to outperform other types of models like ARMA, neural networks, wavelet networks etc. A short-term module was developed based on F-NNs with wind power as input and/or wind speed or direction. F-NN models were found to outperform persistence up to 20% for the first 6 hours.

Long-term: An adaptive F-NN model was developed for this task. Adaptivity permits to take into account efficiently the most recent profile of the wind park production. This is critical in cases where meteorological forecasts are not accurate and indicate a different tendency than what is actually measured – see **Figure 9**. On the other hand, adaptivity provides on-line compensation for changes in the environment of the application like addition of wind turbines, changes in the surrounding vegetation etc.

The artificial intelligence model permits the easy use of various types of explanatory input to optimise results. The model converts directly input to wind park power without intermediate steps. It receives both SCADA data and generic Numerical Weather Predictions as input. The model was configured to operate with the HIRLAM forecasts for wind speed, direction and temperature for different Levels. The long-term module was found to outperform persistence up to 60% for 48 hours ahead. **Figure 10** shows representative results for a wind farm in Ireland for two data sets of 3 months each covering the period 11/2001-03/2002.

B. Wind Power Forecasting Module 2

The RAL Meteo software has been designed to operate in stand-alone mode and has been implemented with a user-friendly man-machine interface for the Electricity Supply Board (ESB) in Ireland. Wind power forecasts are produced on both fast (15 minute intervals up to 8 hours ahead) and slow (1 hour intervals up to 48 hours ahead) cycles. The slow forecast is based on input meteorological wind speed forecast, derived from the HIRLAM model of Met Éireann (see below). This is error-checked, scaled appropriately to hub-height, and then converted to wind power by applying a filter initially based on the manufacturer's power curve. At the same time, wind power production data is collected from the wind farm via the wind farm's own Scada system and used to assess the errors in the wind power forecasts. Once sufficient operational data has been obtained, much improved

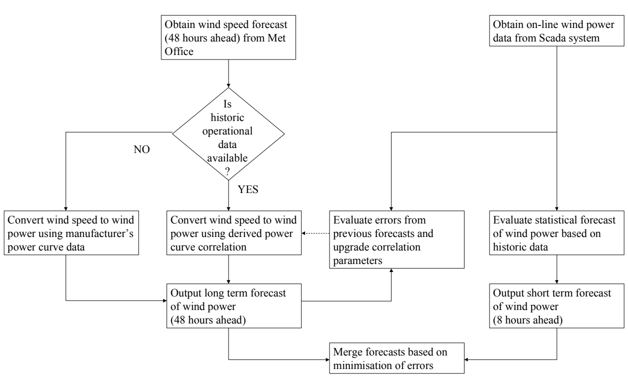

Figure 3: Diagrammatic flow chart of the RAL Meteo Wind Power Forecasting software

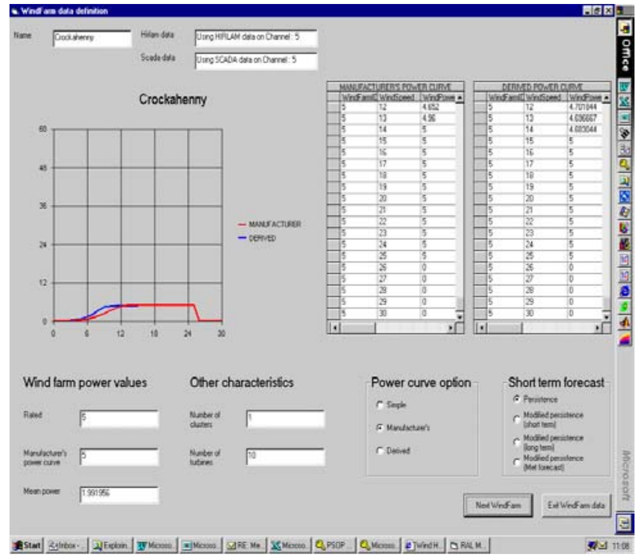

Figure 4 : Screen shot showing the various options for each windfarm

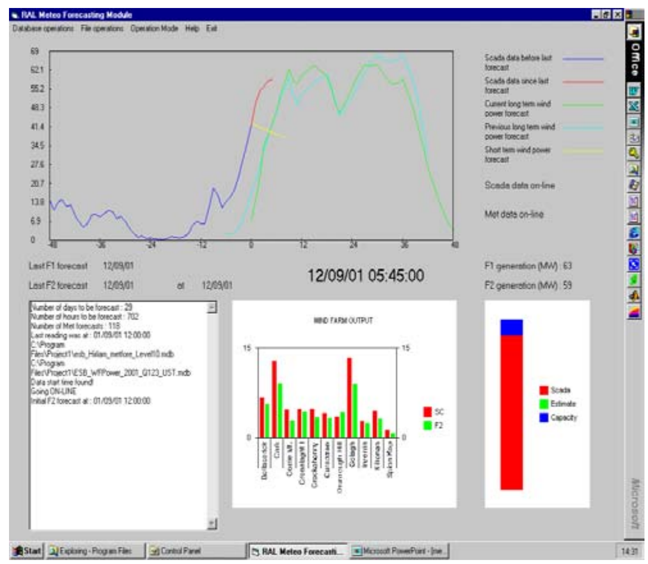

Figure 5: User Interface of RAL module

wind power predictions can be obtained by deriving a new filter based on the historic forecast wind speed and measured wind power data. More sophisticated filters are being developed for the case where wind speed and direction are also measured at the wind farm.

VI. TRIAL INSTALLATION IN IRELAND

The project started in March 2000 and is scheduled to be completed in February 2003. The project is a European R&D project financed within the Energie Programme.

Eleven wind farms totalling 69.49 MW have been selected for analysis in the project. Summary details of the selected wind farms are listed in **Table 1** and shown in **Figure 7**.

The RAL wind-forecasting tool has been operating for a trial period online since 1st July 2002. There are three Power Curve options selectable for each windfarm as shown in **Figure 4**: (1) Simple, (2) Manufacturers, (3) Derived.

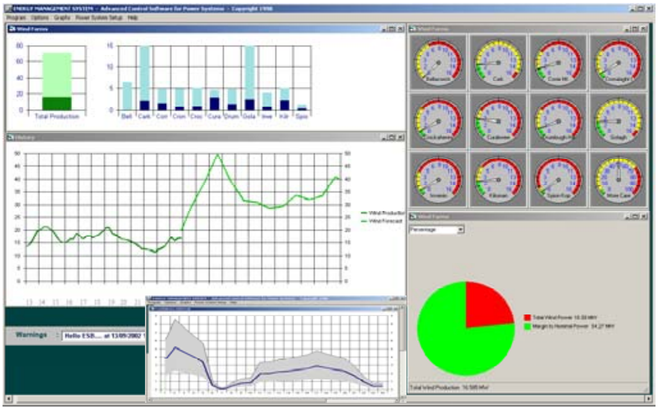

Figure 6: The user interface of the Ecole de Mines wind forecasting module

Table 1: Wind Farm details

Name	Region	Capacity (MW)
Bellacorick	Mayo	6.45
Cark	Donegal	15
Corrie Mountain	Leitrim	4.8
Cranaloght	Leitrim	4.98
Crockahenny	Donegal	5
Curabwee	Cork	4.62
Drumlough Hill	Donegal	4.8
Golagh	Donegal	15
Inverin	Galway	2.64
Kilronan	Roscommon	5
Spion Cop	Leitrim	1.2

Figure 7: Geographical location of 11 wind farms

A typical screen shot of the software in **Figure 5** displays for the total output:

- Present long term forecast
- Previous long term forecast
- Present short term forecast
- Scada data for last 48 hours

and for each individual farm:

- Online Scada values
- Corresponding long term forecasted value

The Armines module has been run in historical mode and tested extensively for the case of eleven wind farms in Ireland with a view to implementing at ESB in October 2002. **Figure 6** shows a display of the MORE-CARE on-line platform as configured to run as a stand-alone wind forecasting application.

VII. RESULTS

A. Evaluation of Hirlam Predictions.

The High Resolution Limited Area Model (HIRLAM) is a numerical weather prediction model run by the Irish Met Office at a horizontal resolution of 33 km with 24 vertical levels. The model runs at 0, 6, 12, 18 UTC each day with a forecast horizon of 48 hours and takes about 4.5 hours to run. The HIRLAM wind data for each wind farm location is then interpolated to hub height from the HIRLAM grid. Met Éireann have been providing the TSO with forecasts since February 2001. These forecasts have all been archived in a database with very few missing forecasts. Since this is such a vital part of the wind prediction software it is excellent that reliability has not been an issue to date. Some re-tuning of the model will have to be done since the HIRLAM model has changed to a high-resolution 16 km grid but these forecasts are expected to be even more accurate.

In the frame of the project, an extended analysis has been carried out to evaluate the performance of the HIRLAM forecasts themselves. Since wind speed measurements were not available, it was not feasible to measure directly the HIRLAM error. For this reason, analysis was based on the correlation between HIRLAM and the measured wind power.

Table 2 gives the cross-correlation coefficients between the measured output of the Cark wind farm and HIRLAM forecasts for that site. Data of the period May-July 2001 have been used. The cross-correlation between HIRLAM wind speed and wind power is high (>0.75). This value confirms a globally good quality of the HIRLAM forecasts. Hence, a reliable basis is available for the wind power prediction models to operate. In other cases studied in the project, characterised by complex terrain, similar analysis gave values lower than 0.660

Table 2: Cross-correlation coefficients between measured wind power and Hirlam wind speed ad direction forecasts.

	1.000								
	0.784	1.000							
	0.789	0.812	1.000						
	0.776	0.837	0.978	1.000					
	0.798	0.930	0.919	0.953	1.000				
	-0.112	0.008	-0.149	-0.109	-0.026	1.000			
	-0.044	0.063	-0.080	-0.046	0.023	0.812	1.000		
	-0.094	0.029	-0.129	-0.092	-0.009	0.914	0.886	1.000	
	-0.116	0.001	-0.151	-0.114	-0.034	0.936	0.840	0.938	1.000

WP: Total wind park power,
U-i, D-i,: Hirlam wind speed, direction forecasts for level i with i=10 for 10 meters, i=22 for Level 22, i=23 for Level 23, i=24 for Level 24.

In order to focus on particular situations, a dynamic approach was developed to examine correlations in detail. The aim is to estimate the probability of situations where Hirlam fails to predict local conditions for a certain period of time (i.e. due to local weather situations). For this purpose, cross-correlation was estimated using a sliding window of 100 hours. Then, the distribution of the obtained values was estimated as shown in **Figure 8**. The range of the values is between {–0.4 to 0.92}. This indicates that one should expect short periods at which, Hirlam forecasts will not be reliable. The frequency of these periods is however limited since the distributions are centered around the 0.8 correlation value.

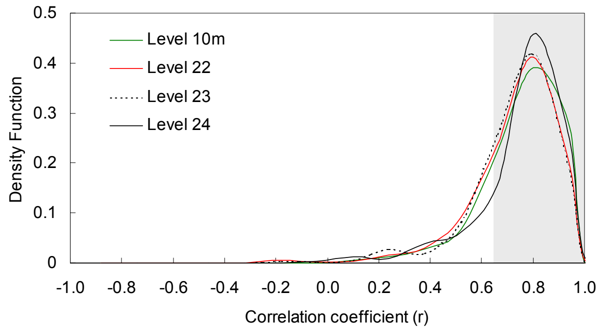

Figure 8: Distribution of correlation coefficient *r*(100) between Hirlam wind speed forecasts and measured wind park power.

B. Evaluation of Module 1

Figure 9 shows a comparison between the performance of the fuzzy model and a simple model based on the conversion of the Hirlam wind speed of 10 m to the hub height and then to power using the machine power curve. The simple model under-predicts power significantly during the first hours. In contrast the fuzzy-neural network model predicts a higher power for the first lower peak of the Hirlam wind speed and captures the shape of the real curve.

In **Figure 11** the improvement with respect to persistence is given. It rises up to 54% according to the time-step. It is important that this improvement is always positive and especially in the period up to 6-10 hours ahead. Moreover, for this period the inclusion of meteorological forecasts contributes to have twice as better performance as the one of short-term models (without meteorological forecasts). In this sense, it becomes evident that the long-term model can replace also short-term models when NWP is available.

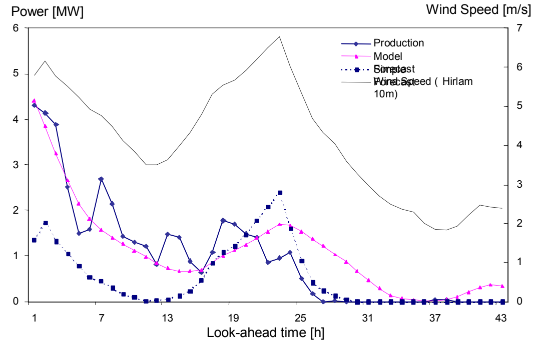

Figure 9: Comparison with a simple model.

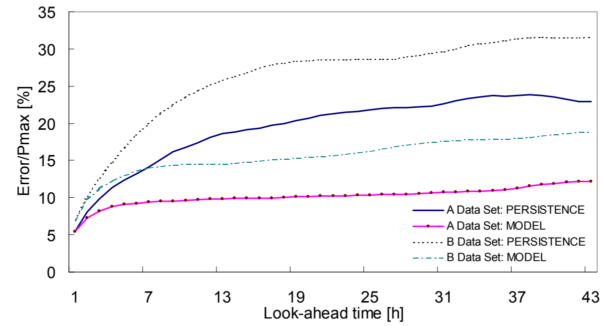

Figure 10: Performance of ARMINES model for a wind farm in Ireland

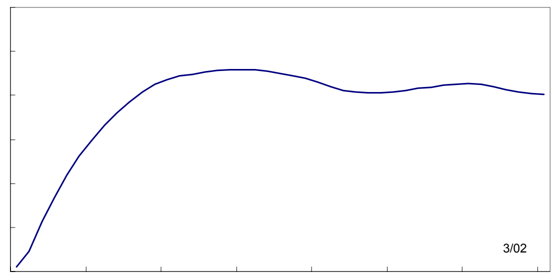

Figure 11: Improvement with respect to persistence.

C. Evaluation of Module 2

Preliminary results from evaluating the RAL Meteo Wind Power Forecasting module against 6 months of historic data (**Table 3**) indicates that significant improvements over persistence can be achieved at all time scales. For long term forecasts, the table shows the improvement (up to 40% improvement over persistence) from using the manufacturer's power curve as a filter, and the considerable further improvement (up to 50%) from using the power curve derived from the historic correlation between forecast wind speed and measured wind power.

Table 3: Improvements against persistence using RAL Meteo Wind Power Forecasting module (preliminary results)

Improvements in RMS error compared with persistence (preliminary results)			
Look ahead Forecast method	**0-8 hours**	**9-24 hours**	**25-48 hours**
Long term forecast (up to 48 hours ahead) % improvement over persistence			
Manufacturers power curve	no data	35%	42%
Derived power curve	1%	51%	53%
Short term forecast (< 8 hours ahead) % improvement over basic persistence			
Persistence - merge with long term mean	4%	-	-
Persistence - merge with Met forecast	12%	-	-

In the shorter term, merging the persistence forecast with the long term mean wind power for the individual wind farms [5] realises an improvement of around 4%. However, wind power forecasts based on the HIRLAM wind speed forecast data perform better than persistence after times as short as 2-4 hours and result in improvements of more than 10%, averaged over the 0-8 hours time band. It must be stressed that these are preliminary results and that further evaluation is being carried out on longer data sets.

The graphs below show a 4-day period for total wind output (**Figure 12**) and an individual wind farm (**Figure 13**) compared with actual metered output.

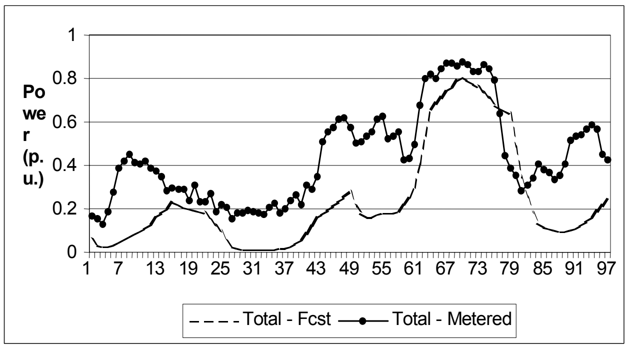

Figure 12: Total wind forecast vs Actual metered output for period 4 Sep 2001 to 8 Sep 2001.

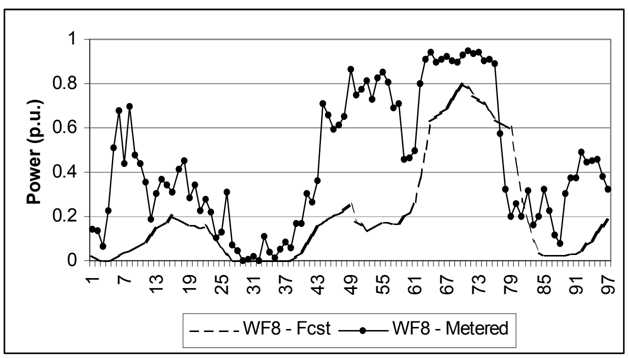

Figure 13: Wind forecast vs actual metered output for one wind farm for period 4 Sep 2001 to 8 Sep 2001.

VIII. CONCLUSIONS

Wind generation has grown to a level where it is impacting on the operation of the Irish power system.

To operate the power system with significant wind generation, the TSO must have an accurate forecasting tool (ideally up to 7 days). With the onset of higher wind penetration and larger windfarms, wind generators must also provide capabilities similar to conventional generators.

RAL's More-Care wind-forecasting module has been successfully running online since July 2002. The initial results look promising and feedback from operators in ESB National Grid has been positive. Further evaluation is required especially in relation to the transition to the higher resolution Hirlam grid.

The Armines software is installed for on-line operation at the islands of Crete and Madeira, where its performance is currently under evaluation. It has been run in historical mode and tested extensively for the case of eleven wind farms in Ireland with a view to implementing in October 2002.

Further work will involve integrating the short and long term models to obtain an optimal performance forecast over the whole horizon of 48 hours.

REFERENCES

[1] Dept. of Public Enterprise, Green Paper on Sustainable Energy, Irish Gov. Publications, Dublin, 1999.

[2] http://www.irlgov.ie/tec/energy/alternative/aervresults.doc

[3] Directive 2001/77/EC of the European Parliament and the Council of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market

[4] G. Kariniotakis, D. Mayer , "An Advanced On-Line Wind Resource Prediction System for the Optimal Management of Wind Parks", Proceedings of the MedPower 2002 Conference, Athens, Greece, 4-6 November 2002

[5] Nielsen, T.S., Joenson, A., Madsen, H., Landberg, L., Giebel, G., *A new reference for wind power forecasting*, Wind Energy, Vol. 1, p. 29-34, 1998

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BIOGRAPHIES

Ruairí Costello was born in Dublin, Ireland in 1978. He received a B.E degree in Electrical Engineering from University College Dublin in 1999. He has been working in Power System Operational Planning in ESB National Grid since 1999. His main work has involved Blackstart and renewables.

Damian McCoy was born in Dublin, Ireland. He received a B.E. degree in Electrical Engineering form University College Dublin in 1992 and a MSc degree also from University College Dublin in 1994. He has worked in Power System Operations, ESB National Grid since 1995. He is a member of IEI. His work includes dealing with the impact of increased renewable energy penetration levels on the operation of the Irish electricity system including work on wind power forecasting methods.

Philip O'Donnell was born in Dublin, Ireland. He received a B.E. degree from University College Dublin in 1982. He has held a number of positions in the system operation area of ESB since then. He is currently manager, Power System Operational Planning.

Geoff Dutton was born in Stockport, UK in 1961. He received a B.Sc. degree in Engineering Science from the University of Durham in 1984 and a Ph.D. degree from the University of Liverpool in 1989. He has worked in the Energy Research Unit (ERU) of CLRC Rutherford Appleton Laboratory, UK since 1989 as a research scientist, including as research manager of the ERU Test Site since 1993. His research interests include hydrogen energy systems, wind power forecasting, and non-destructive testing and residual life assessment of wind turbine blades.

Georges Kariniotakis was born in Athens, Greece. He received his production and management engineering and MSc degrees from the Technical University of Crete, Greece and his PhD degree from Ecole des Mines de Paris in 1996. He is currently with the Center of Energy Studies of Ecole des Mines de Paris as a scientific project manager. He is a member of IEEE. His research interests include renewable energies, distributed generation and artificial intelligence.