Innovative Short-Term Wind Generation Prediction Techniques

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Global Wind Power Market

♦ Wind power is the fastest growing electricity generation technology in the world.

♦ The global wind energy sector experienced another record year in 2005. The year saw the installation of 11,769 MW, which represents a 43.4% increase in annual additions to the global market, up from 8,207 MW in the previous year.

♦ The total value of new generating equipment installed was $14 billion.
The total installed wind power capacity now stands at 59,322 MW worldwide, an increase of 25% compared to 2004.

The countries with the highest total installed capacity are Germany (18,428 MW), Spain (10,027 MW), the USA (9,149 MW), India (4,430 MW) and Denmark (3,122).
Wind power has been growing at around 30% every year since the early 90s.
Europe is still leading the market with over 40,500 MW of installed capacity at the end of 2005, representing 69% of the global total.
However, Australia Pacific is the largest area of growth.
Wind Power in Tasmania

Roaring Forties

Tasmania
Excellent Windfarm Potential
Tasmania is one of the world’s richest regions for wind power development.

Tasmania has the largest number of planned wind farm installations.

Although Tasmania only has a total to a capacity of 67 MW at present, developments underway will take the total to 143 MW and a further 674 MW of wind farm installations are being investigated.

When compared with Tasmania’s average demand of about 1200 MW, this is large.
Tasmanian Wind Power Potential

Tasmanian Wind Recordings

- Average less than 2 m/s
- Average between 2 and 3 m/s
- Average between 3 and 4 m/s
- Average between 4 and 5 m/s
- Average between 5 and 6 m/s
- Average between 6 and 7 m/s
- Average between 7 and 8 m/s
- Average over 9 m/s
Wind power challenges

- Large penetration windfarming is a relatively new occurrence. This poses new challenges.
- A varying supply of generation causes problems with fault ride through capability, security, reliability and power quality.
- Since wind is intermittent, power generated from wind is also intermittent.
There is a tendency to cluster windfarms to take advantage of the best wind sites. This results in heavy strain on transmission networks that are not always reinforced. Thus, operation near the transmission limit will not be unusual.
Wind power challenges
Operating a high wind power penetration system

Generally, a power system is considered to have four time horizons

- Long-term
- Medium-term
- Short-term
- Real time
However, wind operates differently to fossil fuel systems (and hydro for that matter).

The time scale definitions are too long as wind changes frequently (more on this later).

The load (power generation) categories are also unusual for wind power.
Operating a high wind power penetration system

Usually system load has three sub-categories

- Peak Load
- Middle Load
- Base Load
Since windfarm output cannot be increased to cover demand, it can be thought of as a base load.

However, a base load is (by definition) constant, windpower is not.

Another method considers windpower generation as negative demand, also an unusual approach...
Both cases are just models, but both clearly demonstrate the need for accurate short-term prediction.
Since windpower is expensive to store, it is difficult to schedule in the traditional sense.

Furthermore, using huge quantities of spinning reserve is not efficient system operation.

Thus, wind power is best utilised by adopting dynamic operating protocols that require accurate predictions, however…
Operating a high wind power penetration system

Typical Wind Time Series (2 hours)
Operating a high wind power penetration system
Contemporary Forecasting Techniques

Efficient wind power operation needs accurate predictions on multiple horizons:

- 2-3 minute forecasts to handle wind gusts
- 15-30 minute forecasts for dispatch
- longer forecasts for planning.
Traditionally, wind forecasts were only developed for longer periods as the very short-term predictions were of little use.

The wind forecasting systems for wind were designed *without* wind farming as an objective.

*Numerical Weather Prediction (NWP)* models are very advanced and provide excellent results over longer periods, but not for the shorter periods.
Limitations of Numerical Weather Prediction

♦ Predictions from an NWP model have four limiting factors:
  • data variability
  • digital elevation model (DEM) resolution
  • grid spacing
  • computation time

♦ Together these limit the usefulness of NWP for short-term wind power forecasting.
To complement the NWPs, a system called “persistence” was used for shorter-term forecasting periods.

Persistence operates on the assumption that the wind will not change from time $t$ to $(t + 1)$.

$$x_{\text{persistence}} = x(t) = x(t + 1)$$
In wind prediction, statistical methods are generally aimed at producing short-term predictions. They use the difference between the predicted and actual wind speeds in the immediate past to re-tune the model parameters.
The neural network based approaches use large time series data sets to learn the relationship between the input data and output wind speeds.

The accuracy of both statistical and neural network based methods degrade rapidly with increasing prediction lead time.
Hybrid Systems

• Attempt to combine the best aspects of the techniques used.
• Careful thought about the way the system will be combined is important.
• Lotfi Zadeh (the creator of fuzzy set theory) is reputed to have said about hybrid systems...
However…

German police, French mechanics, British cuisine, Italian banking and Swiss love would be a bad one.

“...
Fuzzy systems and neural networks are natural complementary tools in building intelligent systems.

While neural networks are low-level computational structures that perform well when dealing with raw data, fuzzy logic deals with reasoning on a higher level.

However, fuzzy systems lack the ability to learn and cannot adjust themselves.
The merger of a neural network with a fuzzy system into one integrated system therefore offers a promising approach to building very short-term wind prediction models.

A neuro-fuzzy system is, in fact, a neural network that is functionally equivalent to a fuzzy inference model. For example an Adaptive Neuro-Fuzzy Inference System (ANFIS) proposed by Roger Jang is a six-layer feed-forward neural network.
Adaptive Neural Fuzzy Inference System

Layer 1 Layer 2 Layer 3 Layer 4 Layer 5 Layer 6

Layer 1

Layer 2

Layer 3

Layer 4

Layer 5

Layer 6

A1

Π1

N1

1

B1

Π2

N2

2

B2

Π3

N3

3

Π4

N4

4

y

x1 x2
Issues with ANFIS:

- The major problem facing this method is the need for large quantities of data.
- It can be training-time intensive, although once trained, the operation is extremely fast.
To develop an ANFIS, certain parameters must be chosen:

- Number of training inputs
- Number of Membership Functions (MFs)
- Number of epochs (usually small)
- The training data set and the test data set
- Mathematical function for MFs
Developing the ANFIS

♦ The data set must be split into two categories:
  • Training
  • Testing

♦ The training set must be sufficiently varied to train the system adequately.

♦ The test set must be sufficiently varied to test the system adequately.
Choosing Prediction Parameters

♦ When developing a prediction system for wind power purposes one of the most important decisions is to choose which parameter(s) will be forecast.

♦ We should decide whether to predict
  • wind speed alone; or
  • wind speed and direction; or
  • wind vectors.
Choosing Prediction Parameters

♦ Furthermore, we might consider forecasting power output directly rather than the wind speed and then converting it to power output.

♦ Further still, we may try to predict the aggregate power output or the aggregate wind input for the entire wind farm (or maybe even several wind farms).

Choosing the parameter to predict is not trivial...
Predicting wind speed alone is a logical basis to start considering wind forecasting for the purpose of wind farming. A turbine’s power output is governed by wind speed according to the following equation:

\[ P = \frac{1}{2} (C_p \rho A_b \nu_w^3) \]

where \( C_p \) is performance coefficient; \( \rho \) is air dry density; \( A_b \) is swept area of blade; and \( \nu_w \) is wind speed.
This means that to get most efficiency out of the turbine, it should be turned to face the oncoming wind.

- It follows that we need to forecast both wind speed and direction.
- Wind vectors is a more useful approach.
- The forecasts of the wind vectors lost a little accuracy when compared to wind speed, but were much more accurate than trying to forecast wind speed and direction independently.
A turbine’s power output is governed by wind speed:

\[ P = \frac{1}{2} (C_p) \cdot (\rho) \cdot (A_b) \cdot (v_w^3) \]

where \( C_p \) is performance coefficient; \( \rho \) is air dry density; \( A_b \) is swept area of blade; and \( v_w \) is wind speed.

But \( C_p \) is not constant and accordingly, rating curves are usually used.
Power output rating curve for a wind turbine

![Graph showing power output vs. windspeed for a wind turbine.]

- **Y-axis:** Power Output [kW]
- **X-axis:** Windspeed [m/s]
Prediction of wind rather than power output is not tied to a specific machine design, operation or wind farm layout:

- if the generator unit were replaced the predictions based upon power would be invalid.
- if the operators wanted to operate the wind farms in unusual manners such as using wind power to generate ancillary services, or even achieving better maximum power point tracking, power forecast systems would become out-dated.
Another problem with forecasting power instead of wind is that it is much more difficult to get a good data set:

- the turbine may not be facing directly into the wind,
- the blades may be tilted such that they are not catching the full force of the wind, or
- it may simply be decommissioned for maintenance (which will produce data similar to a low wind speed period).
Forecasting over a larger space allows some error cancellation.

An example could be to consider trying to predict the power use from ten houses and predicting the power use from 1000 houses. The 1000 houses will be generally easier to predict.

The same concept is true for wind forecasting.
But you must still ensure that the data being used to develop your system is truly representative of the system.

- Our research has indicated that the data set can be reduced by as much as an order of magnitude when trying to aggregate a circuit of up to ten wind turbines.

- It is a serious problem and in a field where enough data is difficult to obtain, any data set reduction can cause problems.
Data Generation

- When investigating data at wind sites, it became apparent that a large hurdle would be the reliability of the data.
- In fact, some data sets were insufficient to be able to properly train and test a model.
- This was overcome through developing a data generation technique that could reproduce the correlations in a time series data set.
Generating data for training a system in power engineering is not a new innovation. However, the standard method of using a probabilistic model assumes that all variables are very weakly correlated. This is not true for wind generation. Thus, a more sophisticated approach must be developed.
Our research has shown that difference prediction is superior to actual data set prediction.
It was found that at the lower wind speeds, the data was less variable than at the higher wind speeds.

The set of histograms allowed the modeling of increasing deviation with increasing wind speeds.

This was also tested for wind power output (after filtering to ensure that the data was useful).
Aggregated histograms over the entire wind farm
Conclusions

Areas for applications of numerical weather prediction models, persistence models, statistical and neural based methods, and also an adaptive neuro-fuzzy inference system have been considered.

Different prediction parameters such as wind speed, wind direction, wind vectors, and power output have been discussed.

Finally, data generation for very short-term wind prediction has been proposed.
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“Very Short-Term Wind forecasting for Tasmanian Power Generation”
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