QUANTIFYING RISKS IN WIND FARM DEVELOPMENTS

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- measuring and analyzing a wind resource
- quantifying wind resource risk
- quantifying an annually varying energy production

Abstract and background

The installed capacity of wind farms is getting similar to those of conventional power stations. The financing necessary to build these wind farms is getting larger. The financial analysis of such wind farms should thus be robust and should particularly address the quantification of energy produced by the wind farm based on the varying wind resource. It is now time to move away from ‘average’ wind speeds and thus average annual energy productions. The larger investment decisions should be based on confidence levels associated with energy production. This article describes the statistical methodology used to calculate generation output of a wind farm as a function of required confidence levels, for each of the future years in which the wind farm is intended to be operational.

PB Power’s Wind Power and Developing Technologies Group has recently been awarded a further major New Zealand governmental research project aimed at increasing the confidence level of investors and developers in regards to the calculation of future energy production of proposed wind farms. The research undertaken by PB Power, tackles the difficult task of forecasting what the wind resource will be during the operational life of the wind farm, i.e. the wind resource of the future, 20 to 30 years into the future.

The project has been granted based upon the already large amount of knowledge PB Power has accumulated and verified over the years. This document discusses the general methodology and shows the statistical data analysis that PB Power presently undertakes.

As part of the research program, the Wind Power Group is evaluating and developing several different forecasting methodologies including Persistence models, Fast Fourier Transforms, Auto Correlation and Neural Networks. The research has found immediate practical usage in working with financial institutions and developers of wind farms in Europe, China, Australia, the US and New Zealand.

INTRODUCTION

Wind Power continues to be the fastest growing power generation technology in the world. Although only about 15,000 MW of capacity has presently been installed world wide, it has been growing by an average of 35% for the last 5 years.

The continuously changing wind power technology, changing as rapidly as computer technology, is fascinating. It is less than a decade ago that PB Power installed a 225 kW wind turbine, which is now the world’s record holder for 5 years in a row in regards to energy production of that particular model. The 660 kW turbines of the Tararua Wind Power project (the largest wind farm in the Southern

Hemisphere) installed by PB Power in 1998, seem now small in comparison with those installed today. A Japanese project the Group is involved in will use 1.3 MW turbines. Other projects we have and are providing consultancy services for, uses 1.8 MW turbines (Australia), 1.5 MW in the USA and 2 MW turbines in Europe.

The continuous drive to further improve the availability and efficiency of wind turbines, sees technologies utilised from the space age, like super conductor technology, neural networks, permanent magnet generators, counter rotating rotors, smart towers with self adjusting resonant frequencies and so on. Just like computers, the wind turbines of the future will be different from what we see today.

The hardware for and size of wind power projects has changed and with that the wind resource analyses to investigate the financial viability should change as well. PB Power has developed and is using new computer tools to design these power stations of the future.

This presentation will introduce the reader to a refined development process used to establish the future wind resource of a wind farm development. It discusses the quantification of risks associated with the prediction of the future variable wind resource on which investment decisions are based.

WIND ANALYSIS, CROSS CORRELATION AND ENERGY CALCULATION

The following graphs are provided to illustrate some of the processes used to calculate in a statistical sense the future wind resource and the future expected energy production of a proposed wind farm. These calculations are based on a relatively short-term wind resource measurement period at the intended wind farm site. This normally 12-month record will be correlated with a long-term record from nearby meteorological stations. The proprietary multi dimensional correlation process establishes a relationship between the meteorological site(s) and the measurement site. Based on this relationship a historical long-term site record can be established, which forms the input data to the future wind resource and energy production, prediction models. The statistical analysis of the calculated future possible wind resource (in this document the results of the auto correlation methodology is shown) forms the basis for the calculation of the energy output, and thus the financial viability of the wind farm. This statistical approach, based on defined confidence levels, quantifies certainties in energy output of the wind farm for each year of the future lifetime of the wind farm project (20-30 years). This aids greatly the financial modeling of wind farm projects.

Multi Dimensional Cross Correlation

The multi dimensional cross correlation methodology uses short-term data (normally a minimum of 1 year) from the proposed wind farm site. It further uses long term records from ‘nearby’ reference meteorological stations.
The different data sets from the proposed wind farm site and the reference meteorological stations will be cross correlated to establish a relationship between the two wind resources for the period that the measurements were taken at the wind farm site. This is not a straight correlation but will take amongst others into account the direction of the wind speed. The correlation is not based on a straight-line correlation but a curve-fitting statistical algorithm will be used to establish this relationship.

Having established the relationship between the reference site and the wind farm site for the period that measurements were conducted at both sites, PB Power then establishes what the wind resource would have been like in the wind farm for the period for which data was available at the reference meteorological site. In effect we establish a long-term dataset for the anemometer location(s) within the proposed wind farm with the multidimensional cross correlation methodology based on the long-term dataset from the reference meteorological stations.

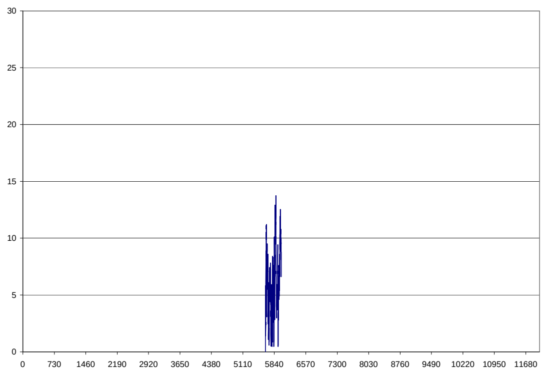
The multidimensional cross correlation methodology thus establishes a long-term record for the anemometer location or locations. It does not provide a ‘long term record’ for the wind farm. The data thus has to be extrapolated from the anemometer location to the whole wind farm area. We are using a multitude of computer programs to establish the area wind flow. This is based on the well-known WAsP analysis tools. In addition, we will use a ruggedness analysis to evaluate the output of the WAsP model and adjust the output taking the local complex topography into account (see section ‘From measurement to area wide wind flow analysis’).

This wind flow over the whole wind farm area will be used in combination with potential wind farm layouts and candidate wind turbines to establish the farm’s annual energy production. It is noted however that the energy production in this case would be based on a long-term wind speed record from the past.

But obviously we are not interested what the wind speed and thus energy output would have been in the past, as we are interested in what the energy output can be in the future, during the future years in which the wind farm will operate[i]. Our statistical analysis tools will provide answers as to how much energy can be (statistically) expected to be produced from the proposed wind farm site for each year of the intended lifetime of the project. These output curves form the basis for financial analysis. These curves are calculated as a function of required confidence levels as shown later in Graph 9.

Note:The following Graphs 1-3 show a time period spanning approximately 33 years. The x-axis is given in number of days (0 through 12070 days).

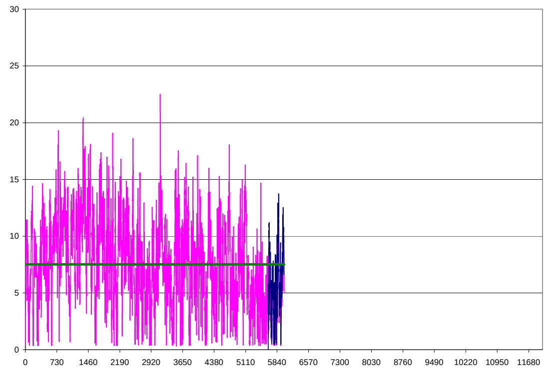
Graph 1 shows 12 months of wind data taken at a proposed wind farm. It only shows data from the top anemometer. For simplicity reasons, data from the lower anemometers are not shown as they are analysed separately. It is further noted that generally several anemometer towers are located within the proposed wind farm area. This document only shows the analysis of one such tower.



Graph 1: 12 months of site measurements

The 12 months of data is correlated with a long-term record. In this example 16.5 years of long term data is shown (day 0 through 6000). The multi dimensional cross correlation identifies a relationship between the data measured at the proposed site and the data from the long-term reference site (data from day 5650 through 6000). The solid line shows the ‘average wind speed’ for the reference site over the past 16.5 years.

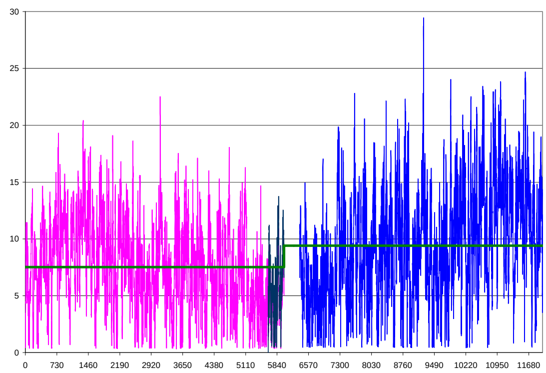
Based on the relationship between the one-year data measured at the site and the simultaneous data from the reference site, the Group calculates what the wind speed would have been at the site during the last 16.5 years. We extrapolate the past historical data to the future. It is the future data that is important for wind farm developers as the future revenue is a function of the future wind speed and not of the past wind speed.



Graph 2: Site and long term measurements

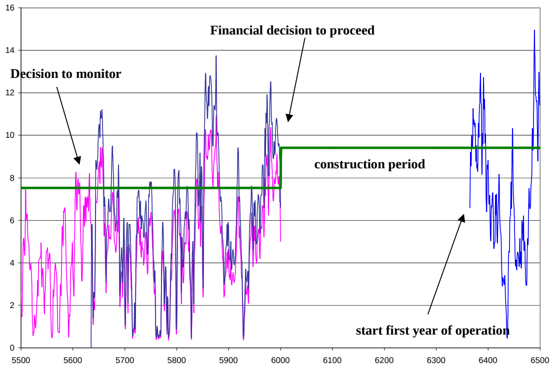
Graph 3 shows one such future possible wind speed profile (right hand side of the graph – light blue). Also shown is what the long term average wind speed will be for the proposed wind farm site (solid green right line). The future wind speed curve (light blue, right hand curve) shows that it is possible that during the first couple of years (after the project starts to generate power), that the wind resource is below the long-term average site wind speed. This clearly means that when financial calculations are made, based on 'averages', that then the revenue during the first couple of years can be far below the 'average'. This could endanger the financial viability of the project (see below in regards to statistical analysis).

Several wind farms required re-financing based on an 'average wind speed' analyses, which is obviously highly undesirable.



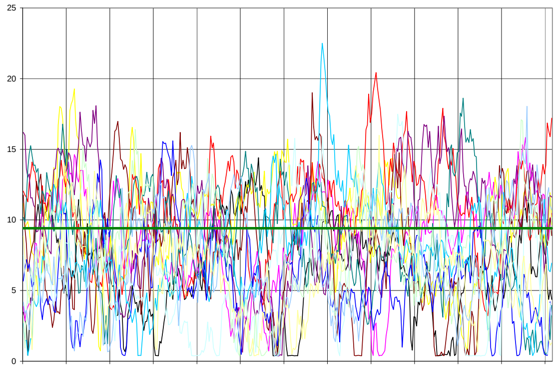
Graph 3: site and long term measurements as well as forecasted wind speeds (15 years)

Graph 4 is an enlargement of the previous graph. It highlights several distinct milestones in the development of a wind farm. The pink curve is the long-term available reference data (shown between day 5500 and 6000). The dark blue is the measured site data (12 months-day 5650 and 6000) and the light blue (day 6350 and 6500) is one possible expected future wind speed scenario. It is noted that after the 12 months of data gathering a financial decision will be made to proceed with the project or not (project milestone). It can then take a year before the wind farm is fully commissioned (depending on size).



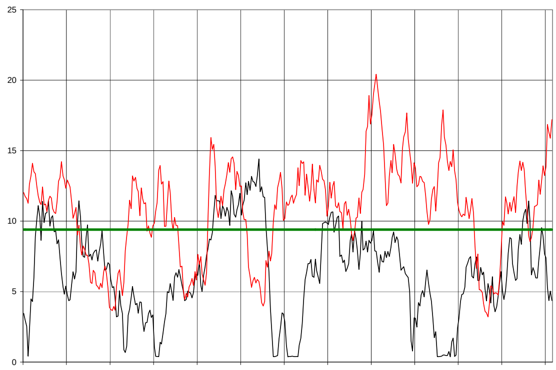
Graph 4: highlighted area with development milestones

Graph 5 shows 13 (!) different possible wind speed traces for the first year of operation of a wind farm (future predicted and calculated wind speeds). It is clearly impossible to accurately state what the actual 'first year' wind speed will be. We can not even say with certainty what the average wind speed will be during the first year of operation (although we can say what the long term average wind speed is, this is shown as the solid line).



Graph 5: 13 possible first year wind speed traces

Graph 6 shows the 'best' and the 'worst' future first year of operation of the proposed wind farm. We can define based on a required certainty that the wind speed will be between the two depicted in this particular graph (based on the above 13 scenarios). We can calculate the confidence level in that statement. This brings us to a statistical analysis.

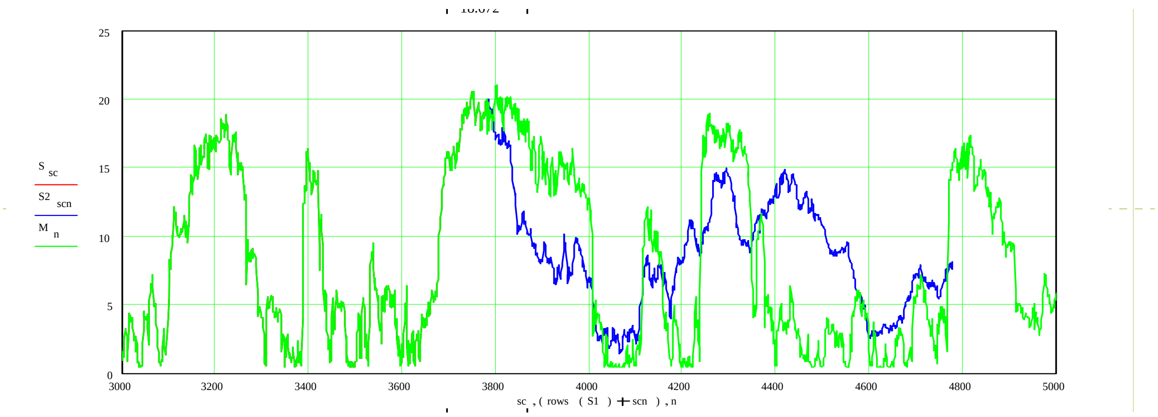


Graph 6: the 'best' and 'worst' first year forecasted wind speeds

The previous graphs contain real information (left side of the graphs). Both the long term wind data and the measured data is actual data. The forecasted data (depicted in graph 3 through 6), has been synthesized based on statistical analysis.

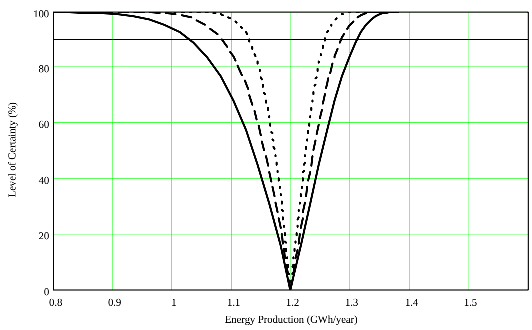
Auto Correlations

The following Graph 7 shows an actual wind speed data set consisting of 5000 samples (green line), however to illustrate the forecasting methodology, it is assumed that no data is available after 3800 samples (only the 'red' data is available for analysis). Beyond this 3800 point, our developed auto correlation methodology establishes a 'future' wind speed trace (blue line). This can easily be compared with the full actual data set (green trace beyond 3800). Statistical analysis of the calculated future wind speed data and measured data are similar. This confirms that the statistical information available in the auto-correlated data can thus be used for future energy calculations. Eventhough the auto correlation methodology has shown great consistency with actual data, the Wind Power Group continues to investigate improvements to further increase confidence levels of investors and developers. This is the objective of the before mentioned research project.



Graph 7 Auto-correlation curve (black line) depicting a possible future wind speed. Future wind speed starts just before 3800 and runs to just before 4800. This curve can be easily compared with the full scale gray curve which is actual measured data.

The following Graph 8 shows a real example of how the future wind dataset has been statistically analysed.



Graph 8: Annual Energy production versus confidence levels

There are three curves depicted in Graph 8. The solid outside curve is the range of generated amount of annual energy for a single wind turbine (as a function of a required level of certainty). In effect this shows, that if we want to be 90% certain in regards to our energy forecast for a single year, that this particular wind turbine would produce between 1.035 and 1.32 GWh/year (i.e. with a 90% certainty we can predict that the energy output is between 1.035 and 1.32 GWh/year).
A lower required certainty would give us a narrower range (y-axis).

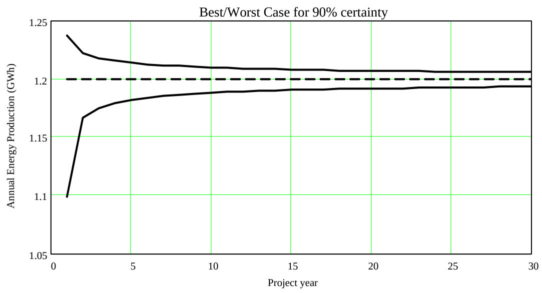
The second line (dashed inside the solid line) depicts the average energy production per year for a two-year period. The inner dotted line is for the annual average energy output for a period of five years.

When combining these curves for 1 and 2 years, up to the intended lifetime of the wind farm project, we can construct a curve with minimum and maximum generation levels for each and every future year of the proposed wind farm as a function of required confidence levels.

Forecasted Energy Levels

This final curve (Graph 9) depicts this combination. It shows that the two curved lines (minimum and maximum production) converge towards the average production (equivalent to the solid wind speed line in graphs 5 and 6). This particular curve has been calculated for a confidence level of 90%, however they can also be calculated for different required confidence levels.

It is this information that is used in a financial analysis. It is important to use this information instead of ‘average’ numbers, as the actual production can be quite less during the first couple of years as seen in Graph 3.



Graph 9: Energy production levels for project lifetime

We recently conducted an investigation for an overseas developer, which has built many wind farms throughout the world. This company encountered financial problems on several of their wind farms during the early years of operation and they asked PB Power to investigate the reasons why. We noticed that the financial analysis for the troublesome wind farms, in the past, was conducted based on ‘average wind speeds’ and thus averaged energy productions.

We conducted the above analysis based on the initial data that was available before the wind farm was build. We then calculated energy production levels for each year of the then proposed wind farm for three confidence level (70, 80 and 90% respectively). Actual production data for the first two years of operation of 2 wind farms and 3 years of data for the third wind farm was then inserted in the graphs. These actual data points for the first year of operation was below the average but slightly above the worst case energy production (above the lower curve of Graph 9). The averages of the two years as well as the average of the 3 years data was again slightly above the minimum energy production curve. This analysis showed again the validity and importance of this statistical approach. If this approach had been taken during the development of these wind farms then the wind farm companies would have known before operation started what the minimum energy production levels could have been.

This statistical approach, which is presently been further refined, has been successfully used on all the major wind farm installations that PB Power has been involved in during the past 3 years. It was used for the before mentioned Tararua Wind Power project to provide a high level of confidence so that the forecasted energy production levels would really be met. This project has been delivering electricity below US 2.5 c/kWh in a non-subsidised and de-regulated electricity environment. It is the largest wind farm in the Southern Hemisphere.

FROM MEASUREMENT TO AREA WIDE WIND FLOW ANALYSIS

This article only illustrates a part of the design process that PB Power normally undertakes. Of similar importance is the extrapolation of the measured and cross correlated data from a single (or multiple) anemometer tower(s), which is in effect a 1-dimensional measurement, to a flow field encapsulating the whole wind farm area. The energy produced by a wind turbine is a function of the wind flow through its rotor disk. The energy produced by a wind farm is further a function of the lay out and energy production of each individual wind turbine within the wind farm. Because wind measurements have only been taken at a single (or a few different) points within the wind farm area (1D), the single point data needs to be extrapolated to a 3D envelope in which the turbines operate.

PB Power conducts wind flow analysis using WAsP computer software. However when the local topography of the proposed wind farm is complex, errors of up to 20% can occur[ii]. These errors are obviously too large for proper energy and financial calculations. PB Power uses corrections to the WAsP model's output using proprietary software to account for these errors in WAsP when used in a complex terrain (ruggedness analysis). In addition multiple short term cross-correlated anemometer measurements are being used to further calibrate the ruggedness adjusted wind flow output.

An additional source of error in conventional energy capture analysis is the accuracy of the theoretical (or measured) wind turbine generator (WTG) power curves. These power curves are supplied by the WTG manufacturers and depict the relationship between the average wind speed and average power production. They are given for specific standard temperature, pressure and (new and clean) turbine conditions. The region of the power curve near the shutdown wind speed is likely to introduce additional errors in conventional energy calculations due to the characteristics of the WTG controller (hysteresis effect).

PB Power has developed, based on its extensive experience in wind flow over and energy calculations in complex terrain, proprietary software that takes the above issues into account (blade dirt accumulation, hysteresis effect, temperature and pressure) and quantifies in the end the uncertainties associated with the energy calculations.

The final energy calculations will include statistical analysis (as depicted in Graph 9), which provides minimum energy production levels for <u>each and every</u> year of the project lifetime. Confidence levels will then be attached to the minimum energy generation curves.

CONCLUSION

The methodology described above, which calculates statistically the energy production of a wind farm has played pivotal roles in many wind power projects that PB Power has been involved in such as the largest wind farm in the Southern Hemisphere: Tararua Wind Power. It was also used in China for the evaluation of four large wind farms for the Asian Development Bank. It has also played a main role in the development of the Windy Hill project (the largest installation in Australia) where after only 3 months of wind data measurements, the decision was made to start construction of the first phase. Testimony to the accuracy of the methodology is the fact that the Windy Hill site will now be doubled in capacity based on additional wind speed information, which was compared and found to agree with the forecasted data, based on the aforementioned 3 months of wind measurements.

The methodologies (statistical analysis as well as the ruggedness analysis) are now being further tested and improved by PB's Wind Power Group as part of a large governmental sponsored research project.

ABOUT THE WRITER

Paul van Lieshout is the Engineering Manager for the PB Power's Wind Power and Developing Technologies Group. He invites you to discuss with him your wind power development and financing plans.

Paul recently relocated to the United Kingdom where he established a major new wind power centre for PB Power. With the addition of this wind power office in Newcastle, PB Power has now 7 wind power offices as part of their global network of 250 offices worldwide including in Turkey. The Wind Power group has undertaken wind power projects in Turkey.

Endnotes

[i] It is noted that the imaginary past performance of a wind farm will provide a fairly good understanding about what energy levels can be expected from a proposed site.

[ii] Standard WAsP wind flow software has been designed for smooth terrain where the wind flow stays attached to the surface. This terrain is normally encountered in Northern Europe and wide-open spaces like Minnesota and Texas. Due to the ruggedness of complex terrain, dis-attachment of the wind flow can occur. When flow separates, errors in this software can occur (in wind speed) in the order of +/- 20% (this is even larger in energy production). It is thus paramount that in complex topography a ruggedness analysis is conducted to avoid such large errors and thus uncertainties. It is further important that the ruggedness analysis is being carried out in high wind speed site even if the sites are from a topographical point of view less rugged.