ANALYTICAL TECHNIQUES FOR UNDERSTANDING THE PERFORMANCE OF OPERATIONAL WIND FARMS

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ABSTRACT

There are indisputably good reasons for understanding, in great detail, the performance of operational wind farms. This can be achieved by collecting sufficient data with a good SCADA system, careful management of this data and intelligent interogation using the techniques described in this paper. SCADA data can be used to graphically represent a wind farm's operation using a time lapse animation. This gives a 'bird's eye view' of a wind farm's historical performance over a meaningful time period for example, one month. It is also possible to identify changes in power performance. Once a change in performance or period of downtime is identified, it is possible to then quantify the amount of lost energy, or indeed gained. These techniques also permit any energy discrepancies to be quantified and categorised in terms of, for instance, power performance, availability, windiness and long-term mean wind speed. Assuming that any identified problems are subsequently corrected the existing long-term energy forecast can be readdressed. This requires the introduction of a wake free-reference wind speed and a wind farm power curve technique. The uncertainty associated with the resulting prediction of long-term energy production can be very low, leading to, in certain circumstances, significant financial benefits.

1 INTRODUCTION

The prospect of improving the energy production of operational wind farms is clearly an attractive one. Most SCADA systems are capable of collecting appropriate operational data, but few integrate all the tools required to fully understand how the wind farm is performing and identify areas, some of which are quite subtle, which could be improved.

The techniques presented in this paper have been developed by Garrad Hassan over the past 10 years during our analysis of SCADA data from some 1000 MW of operational wind farms. They have been used in the context of:

- Identifying areas where performance could be improved;
- Diagnosis where production is not up to expectations;
- Valuation / re-valuation of projects during finance / re-finance;
- Energy predictions following repowering.

The economic implications of these techniques can be huge and the market for them is a very active one.

Presented in this paper is a summary of the following techniques:

- Time lapse animation;
- Power performance and availability tracking;
- Whole wind farm power curve.

Some of Garrad Hassan's experiences are then discussed, together with the relative merits of the techniques. Much of the work in this area focuses on the following four key factors effecting energy production:

- Turbine power performance;
- Availability;
- Windiness;
- Long-term mean wind speed.

2 SCADA OVERVIEW

A SCADA system typically records wind speed and direction data measured at each turbine as well as project metrological masts. The power from the turbine is often recorded at each tower base and also at the point of grid connection. Additionally, the SCADA system records the operating state of the turbine identifying whether or not it is available to operate.

These are the primary parameters which we are concerned with for this type of analysis.

SCADA systems will record many other turbine and mast parameters some of which may be beneficial in the analysis that is described. For instance, blade pitch angle or turbine rotor speed. Ambient temperature and pressure measured at the meteorological masts are used for the calculation of density which is relevant in the power performance analysis.

SCADA data is generally archived on a ten minute basis resulting in very large databases which can be very difficult to manipulate and interpret. For example, one year of data from a large wind farm can be several gigabytes in size, holding millions of records.

3 GRAPHICAL ANIMATION TECHNIQUE

The graphical animation technique has been developed to allow a visual overview of the wind farm performance over a meaningful operational period. Typically this may be run at the end of each operational month. The animation directly uses the 10 minute average turbine data recorded by the SCADA system.

Figure 1 shows a freeze frame from an example of an animation of a group of turbines in the centre of a large wind farm.

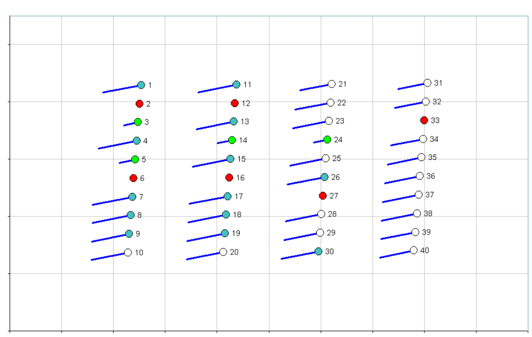

Figure 1 Freeze frame from a windfarm animation

Each circle represents an individual turbine in its real grid position. The bars represent the power of the turbine and the direction that the turbine is pointing. Colours appear in the circles representing the operating state of the turbine. White appears when the turbine is operating below rated, light blue when operating at rated, light green when it is constrained to a power lower than rated and red when the turbine is not available to operate. This technique can be used over a selected time period with each frame of the animation representing a 10 minute period.

The benefits of this technique are that it allows the viewer a good overview for the wind flow through the wind farm highlighting the pattern of topographic and wake influences. It also illustrates the distribution of unavailable turbines. The animation can highlight, in certain circumstances, poor power performance of individual turbines. In Figure 1 we can clearly see that Turbines 3, 5, 14 and 24 are all running in a constrained mode which reduces overall energy production.

4 POWER PERFORMANCE

For identifying changes in power performance, detailed data analysis is required. This is most efficiently done on an individual turbine basis. The nature of this part of the work may require a significant amount of manual input and in most cases investigation shows normal operating performance of the turbine.

There are many causes of changes of power performance, including pitch control malfunction, blade damage or fouling, control program problems, blade angle resetting, aerodynamic enhancements or, as seen in the animation in Figure 1, constrained operation. Some causes may be unintentional or as a result of deliberate intervention by the wind farm operator.

The following example illustrates constrained operation, but it is important to note that this is only one of the many modes of degraded power performance which can be revealed using this technique. Constrained operation is applied in this case to protect the components of the turbine from high loads that arise from operating at or near rated power. In this respect constrained operation is classed as a performance change that is caused by deliberate intervention.

Figure 2 shows approximately one year of ten minute average SCADA data, with the nacelle wind speed on the X axis and the turbine power plotted on the Y axis.

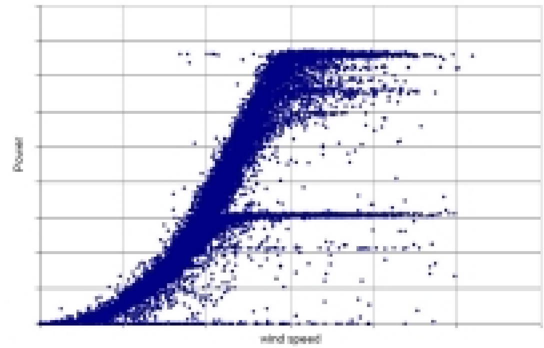

Figure 2 Example of a turbine with constrained power performance

The normal operation pattern of the turbine can clearly be seen. However, the turbine is constrained for a large proportion of the time at different power levels less than the rated power.

The next step is to isolate the periods of poor performance. Figure 3 shows these periods of poor performance shown in green. They were identified by analysing the blade pitch angle of the turbine. The red points on the chart represent time that the turbine was registered unavailable for part or all of a 10 minute period.

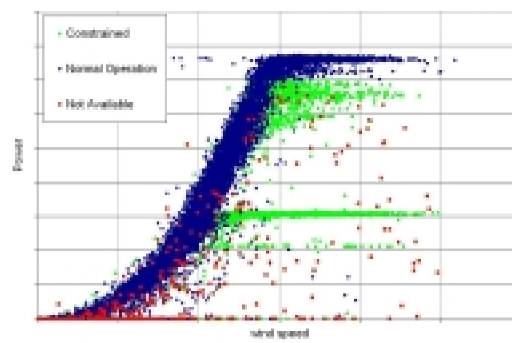

Figure 3 Example turbine with identified periods of constrained power performance

By plotting the data as a time series, as shown in Figure 4, discrete periods of constrained performance can be identified. In this case, the constraint appears to have been removed, permitting several months of normal operation.

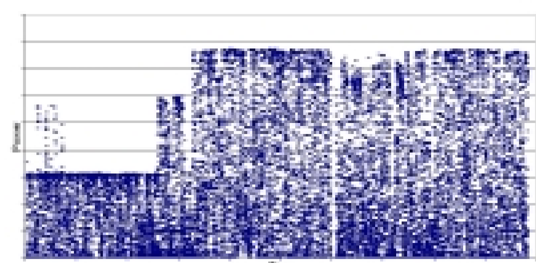

Figure 4 Example turbine showing the time series of power

Filtering the dataset to remove these periods of constrained performance permits an understanding of the non-constrained operation of this turbine, as illustrated in Figure 5.

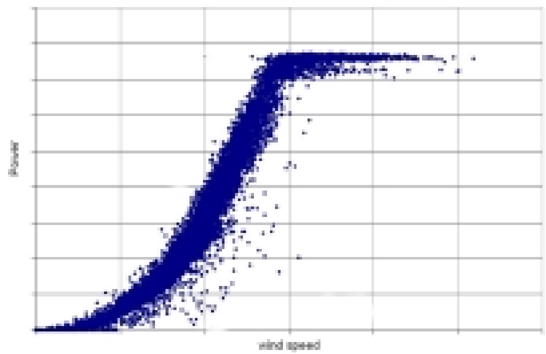

Figure 5 Example turbine with constrained power performance removed

It is common to need to evaluate the quantity of energy lost due to periods of constrained power performance.

Figure 6 shows binned power curves for both the complete dataset and the filtered dataset with all the constrained periods removed. By applying the operational period wind distribution to both power curves and taking the difference the amount of energy lost can be estimated.

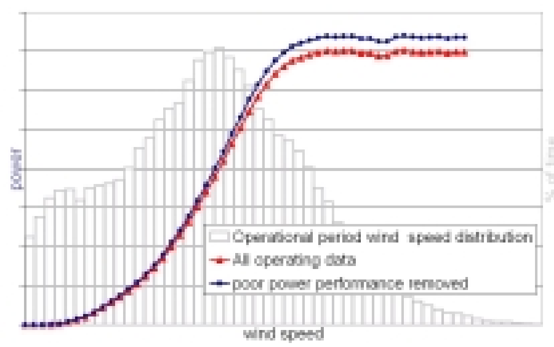

Figure 6 Binned power curves and operational period wind distribution

5 AVAILABILITY

When assessing the amount of energy lost due to availability it is useful to consider a term Down-Time Availability (DTA). This is defined here as the period of time that the turbines were fully available to operate as a fraction of the total time.

It is very important to understand that DTA is a different measure to the 'turbine manufacturer's reported availability'. All down-time, regardless of the reason of the fault that caused it, is accounted for in DTA, but faults like Force Majeure and grid outage may be removed from the calculation of manufacturer's availability.

DTA can be calculated from the SCADA data either by using cumulative counters or 10 minute average data.

To give confidence in the reported availability figures it is possible to perform an 'availability check'. This is done by counting the number of points when the wind speed is higher than cut-in, as measured by the nacelle anemometer, and the power is zero or less. These points are shown highlighted in red in Figure 7. This count, taken as a fraction of the total number of data points above cut-in wind speed, can give a good indication of the percentage of down-time. It should be noted that this does tend to be an underestimate as a data point is only considered 'unavailable' if there is absolutely no production for the whole 10 minute period.

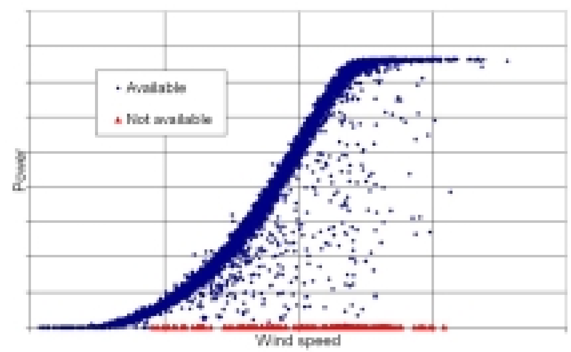

Figure 7 Example power curve showing the availability check

This technique can be very useful when there is some uncertainty in the availability cumulative counters but it does rely on good SCADA data coverage.

An important factor which can be evaluated at this stage is the correlation between downtime and high wind speed. For example, in certain circumstances, enforced utility down time can tend to occur during high production periods. The consequences of such a positive correlation would be higher energy losses than indicated by the reported availability figures based purely on time counters.

6 THE WIND FARM POWER CURVE TECHNIQUE

Conventional pre-construction energy prediction techniques start with an analysis of historical wind data. Once an understanding of the past wind flow over a site has been attained, projections can be made of wind speeds and energy production going forward.

In the same way, post-construction energy predictions are based on historical performance data. Once a detailed understanding of past performance has been attained, using the techniques described above, it is possible to project forward to predict long-term energy production. Garrad Hassan utilise a wind farm power curve technique for these types of prediction.

To create a power curve for the whole wind farm that is related to the wind speed and direction at a single location there is a need to introduce a wind speed at a reference mast. The chosen mast should be wake free, exhibit reasonable data coverage and should ideally have been measuring consistently for a long period prior to the wind farm construction. If this is not available, a combination of masts may be used. Data from these masts may or may not be recorded by the SCADA system.

It is firstly necessary to filter out the periods of poor power curve performance (as discussed above). The next step is to filter out periods of low turbine availability.

To produce the wind farm power curve the average wind farm power in each 1 m/s wind speed bin as measured by the reference tower should be calculated. Given sufficient data, a power curve for each 30 degree direction sector is created.

Figure 8 shows an example of a wind farm power curve presented for eleven, thirty degree sectors. The differences in these curves is mainly due to variations in topographic and wake efficiencies from sector to sector.

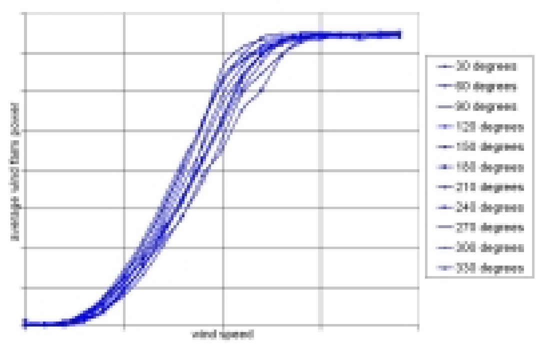

Figure 8 Example wind farm power curve for each 30 degree direction sector

Once the wind farm power curve is created, it is possible to apply it to a wind speed distribution to obtain an energy figure. This can be performed in two main steps. First, the wind speed distribution as measured at the wake free reference mast over the operational period can be applied to the wind farm power curves to establish the expected energy given the wind conditions. Second, the wind speed distribution over a much longer period, including measurements prior to wind farm construction, can be applied to establish the long-term expected energy.

The resulting energy figures represent the energy given 100% availability and a power performance that can be expected in the long-term, assuming that any causes of historically poor power performance are not expected to recur.

The great advantage of this technique is that it effectively removes the need for:

- Topographic modeling;
- Wake modeling;
- Assumptions regarding turbine power performance;
- High accuracy and extensive wind speed monitoring.

As these are often the main sources of uncertainty in pre-construction energy analyses, the wind farm power curve technique generally results in predictions with very low uncertainties. This is a considerable benefit for the project, especially if post-construction finance or re-finance is pursued. It is worth noting that several developers are including preparation for a possible wind farm power curve analysis at the very start of their development plans. Early, careful planning ensures that the lowest possible uncertainties can be attained.

Experience and limitations

Over 1000 MW of operating wind farms have been analyzed by Garrad Hassan by using these and other SCADA data analysis techniques.

Power performance and availability issues have been identified and quantified in terms of energy. In most cases a new long-term estimate of the energy production has been calculated using the wind farm power curve method and the uncertainty in long-term energy estimates have been significantly reduced.

As with every analysis there are limitations in applying these techniques. There is increased uncertainty if there is low SCADA data coverage or a lack of consistency in the SCADA data. Also the wind farm power curve technique requires a wake free wind speed to be applied reliably. Unfortunately, this is not always available.

7 CONCLUSIONS

There are indisputably good reasons for understanding, in great detail, the performance of operational wind farms.

This can be achieved by collecting sufficient data with a good SCADA system, careful management of this data and intelligent interogation using the techniques described in this paper. The results may include:

- Subtle improvements in energy production;
- Understanding any deviations from expectations;
- If appropriate, revaluation of project with a low uncertainty prediction.

These potential benefits can be maximised by early consideration in the development process.