Availability Trends Observed At Operational Wind Farms
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Abstract

Garrad Hassan and Partners has conducted an investigation into how operational wind farms have performed in terms of availability. This paper outlines some of its key results.

The investigation used Garrad Hassan's experience over the past decade assessing the performance of over 14,000 MW of operating wind farms which is approximately 15 % of the total worldwide installed capacity.

Garrad Hassan has gathered together significant information on the performance of wind farms when conducting analyses on behalf of lenders, owners and other parties. With this information, the authors created a database which consists of over 1000 wind farm years of availability statistics with all major turbine manufacturers represented in the dataset. The availability information covers more than 250 wind farms across Europe, US and Asia with periods of operation ranging from 1 year up to 15 years. It is this database that has been used and referenced in this paper to draw relevant observations and conclusions.

The definition of availability data discussed and used in this paper is 'System Availability' and includes downtime associated with the electrical connection system and the grid. It is noted that this availability measure will always result in lower availability levels than 'Turbine Availability' alone.

A distribution of average wind farm availability figures is presented, together with plots showing how wind farm availability varies over time and with wind speed, highlighting the tendency of wind farm availability to 'ramp-up' over time as teething issues are resolved.

An insight is given on how wind farms perform as they reach maturity.

Finally, commentary is provided on how the results can be used to understand the risks associated with availability at all stages of wind farm development from conception to financing and into operation.

Keywords: Availability, Operational Wind Farms, Performance.

Introduction

The availability of a wind farm is directly related to revenue, therefore understanding availability that can be expected over the lifetime of the wind farm is essential in managing the performance of a project and quantifying its value. Over the past 10 years, Garrad Hassan has assessed hundreds of operating wind farms worldwide and it has been noted that many of these wind farms have suffered low levels of availability while others maintained high availability.

To enable an understanding of the expected availability of a new wind farm project, this paper proposes that if the probability of occurrence of a particular level of availability on historical wind farms was known then this could be used to aid understanding of the risks on a new wind farm project. Such information is additional to the “standard” availability forecast methodology currently used and would provide potential validation of current availability assumptions.

Using work completed for wind farm owners and lenders, Garrad Hassan has gathered a large amount of operating data. It is this independently validated data that has been used to derive and summarise historical availability trends in an attempt to answer some key questions:

- What level of availability can be expected throughout the operating life of the wind farm?
- How do turbine size and number of turbines on the wind farm impact availability?
- Does availability reduce at high wind speeds?

Definition of Availability

There are two main definitions of availability: Turbine Availability and Wind Farm System Availability. Clarifying the definition of availability is important; often only one type of availability, Turbine Availability, is quoted when discussing the performance of a project. As discussed below, this may be very misleading when trying to understand the true impact of availability on a wind farm project.

Turbine Availability is a measure of the turbine system only and is the focus of contractual warranty arrangements. This availability excludes wind farm system downtime such as grid down-time and force majeure. This definition often includes an allowance for routine scheduled maintenance such as annual service. This allowance varies from project to project but allowances of 60 hours a year, or approximately 1% of time, are common. Clearly, turbines cannot generate revenue when shut down for maintenance. The definition of Turbine Availability is negotiated on a project by project basis before project construction and so there is no “standard” definition of Turbine Availability. This presents two significant problems. First, attempting to use this as a comparative measure across a range of projects may be misleading. Secondly, Turbine Availability does not reflect total down-time and therefore the true energy losses of the turbine or the wind farm system.

There is an IEC working group, set up in 2007, with the aim of producing a standard to outline a common definition of availability down-time categories. Until the resulting standard is issued there remains no internationally agreed definition of availability.

System Availability more closely represents the true amount of time that the wind farm as a whole is available to generate. The majority of down-time counts against availability, regardless of the cause, and only shutdown due to normal operating conditions is excluded, for instance high wind shut-down or cable unwind events.

The definition of System Availability may be summarised as follows:

$$\textbf{\textit{System Availability}} = \frac{\textbf{\textit{Time that the turbines were available and ready to operate}}}{\textbf{\textit{Total time in the period}}}$$

System Availability most closely represents the availability used in the financial models of a project. A System Availability of 97 % represents 97% of time that the wind farm is ready to produce project revenue. Using these definitions it follows that the Turbine Availability will always be higher than the System Availability. It is System Availability that lends itself to comparison from project to project and it is System Availability that is the focus of the trends presented in this paper.

Compilation of a database of availability statistics

Working for banks, developers and owners, Garrad Hassan has assessed over 14 GW of operating wind farms, which, at the time of writing, is approximately 15% of the world's installed capacity. From this, a database of availability statistics has been created with the aim of identifying trends in the historical data that may be used to understand the levels of availability that may be expected from a new project.

In summary, the database consists of and represents:

- Monthly Turbine and System Availability statistics for over 250 wind farms across the world;
- All major wind farm markets with varied climatic conditions;
- All major turbine manufacturers with turbine rated capacity ranging from 300kW to 3MW;
- The wind farms sizes from 1 or 2 turbines up to well over 100 turbines;
- Varying operational periods for wind farms from between 1 and 15 years.

The information has been subject to a quality checking process. In most cases the data have been subject to validation through detailed analysis of 10 minute average SCADA data and fault logs.

Results

Distribution of Annual Availability

The dataset shown in Figure 1 is the distribution of annual availability. This distribution gives an insight into the frequency of occurrence of different levels of availability that have been seen historically, and demonstrate how realistic the industry standard of 97% availability is.

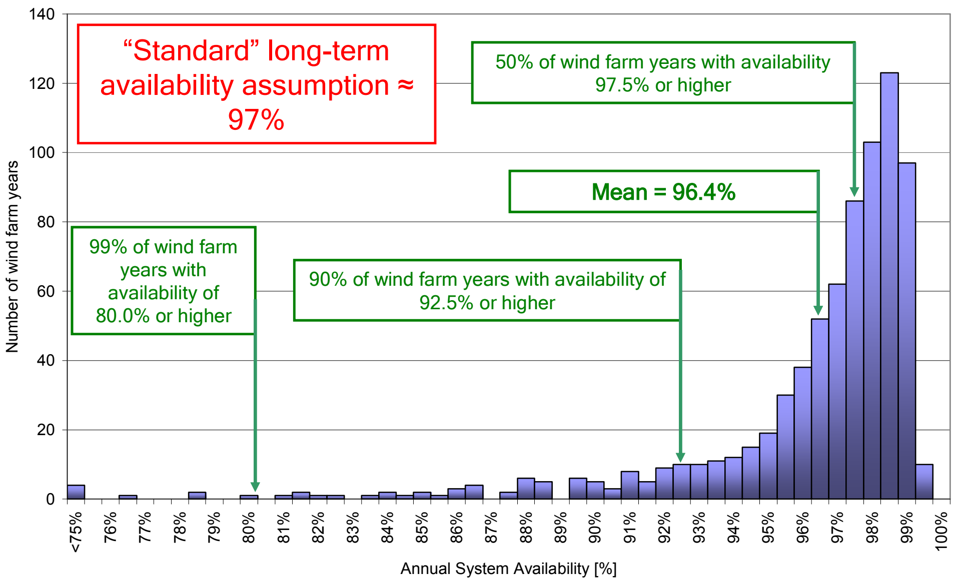

Figure 1 Distribution of average annual availability

The average annual availability is shown on the x-axis and the percentage of wind farm years in the database is shown on the y-axis. It is clear that the distribution is not Gaussian; it is very much a skewed distribution. The mean of the distribution is 96.4%, which is close if a little lower than the industry standard. However, due to the skewed nature of the distribution the 'most likely' availability is higher than this level. In fact 50% of the wind farm years are 97.5% or higher. 90% of the wind farm years are above 92.5% and only 1% of the dataset is below 80% availability.

It is immediately obvious that this dataset has the potential to be used to understand the probability of occurrence of a low availability on a wind farm. However this does not give the whole picture; the database contains availability from wind farms that vary in the operating life-cycle; an therefore it is important to consider how availability varies with time. This is discussed in the following section.

Variation in System Availability over time

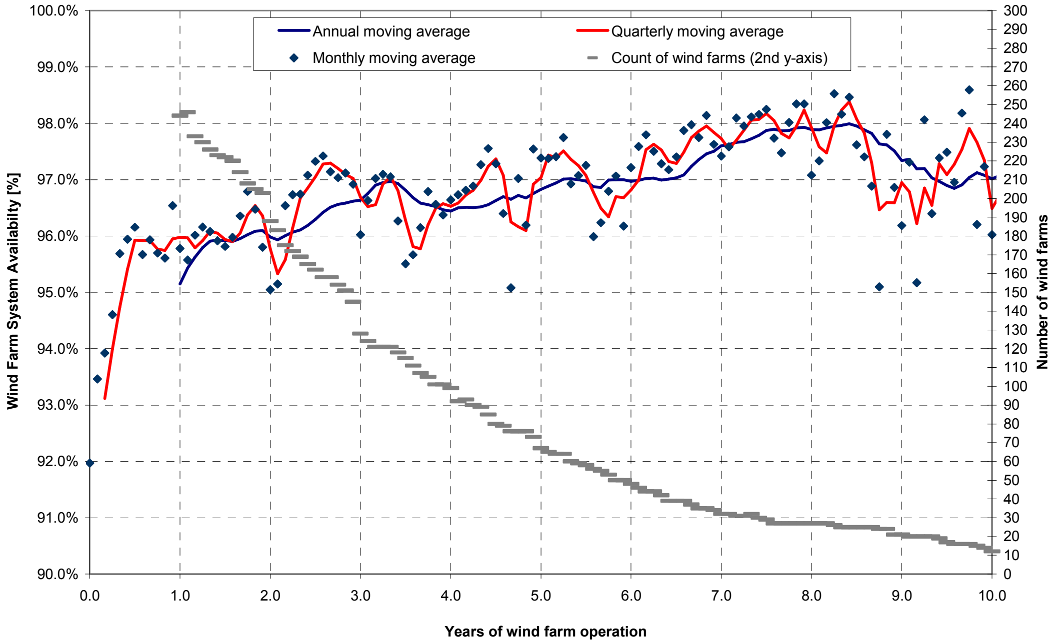

Figure 2 Availability versus time trend; shown monthly, quarterly and annually

Figure 2 presents availability versus the years of wind farm operation, with zero being the commissioning date. The individual solid points show the average availability for all wind farms in the database for each month since commissioning. The diminishing dashes show the number of wind farms in the database that make up the individual monthly availability figures. Also shown, as solid lines, are the quarterly and annual moving average availability. It can clearly be seen that the availability of the wind farms 'ramps up' over time as teething issues are resolved. On average, the wind farms show availability of approximately 93% in the first quarter of operation, rising to close to 96% from the end of the second year. Beyond the end of the second year the availability remains broadly constant at between 97% and 98% as far as the end of year 10. The increased volatility between year 8 and 10 is due to the reducing number of wind farms in the database.

Beyond year 10, the picture becomes very unclear as there are few wind farms in the database that have operated beyond this date. However, Garrad Hassan considers it prudent to assume that O&M budgets should be increased beyond year 10 in order to maintain higher levels of availability.

As noted in the previous section, the most likely availability is actually higher than the average trend as there is a non normal distribution under-lying each of these data points.

The presented trends are dominated, particularly in the latter years, by the previous generation of sub MW turbines; therefore, it is important to understand if the performance of sub MW turbines on generally smaller wind farms is representative of the latest generation of larger multi-MW turbine wind farm projects consisting of more turbines.

Do large turbines and large wind farms result in lower availability?

Figure 3a shows System Availability for the first three years of operation with the database subdivided into sub-MW and MW-plus turbines. It is apparent that there may be more teething issues associated with the larger turbines, which are generally more complex, but once these issues are resolved a similar level of availability can be expected to the sub-MW turbines.

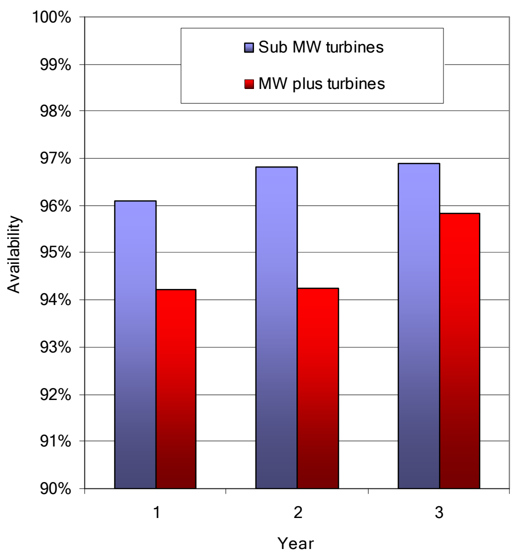

Figure 3a Availability vs. turbine size

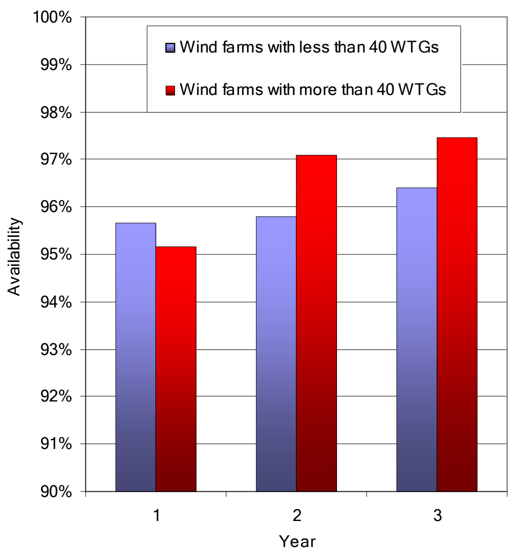

Figure 3b Availability vs. wind farm size

Note 1: Approximately 60% of the wind farms in the database are for sub MW size turbines.
Note 2: Approximately 30% of the wind farms in the database have 40 or more turbines.

Figure 3b shows the equivalent chart, but this time showing the database subdivided by the number of turbines on the wind farm; those consisting of less than 40 turbines and those consisting of more than 40 turbines. Although rather an arbitrary split, it could be considered that at 40 turbines or more a full-time on-site crew becomes a necessity. Lower availability levels due to initial teething issues are more evident in the first year at the larger wind farms. However, by the second year of operation a higher availability average is evident.

It can be concluded from these plots that availability is relatively insensitive to turbine and wind farm size once initial teething issues have been resolved in the first year or two of operation.

Does availability reduce with wind speed?

One important question that is commonly asked is, “does availability decrease with increasing wind speed?” or, “does 1 % of downtime result in more than 1% of energy production loss?”.

In order to study availability versus wind speed it is necessary to interrogate the 10 minute average operating statistics recorded by the SCADA system. A subset of 25 wind farms was selected with geographically diverse locations, varied turbine type and wind farm size as well as varied climatic conditions.

For each wind farm, one year of operating data were subdivided into wind speed bins 1m/s in width. The System Availability was calculated in each of the bins over the normal operating range. Figure 4 shows the combined result for all 25 wind farms.

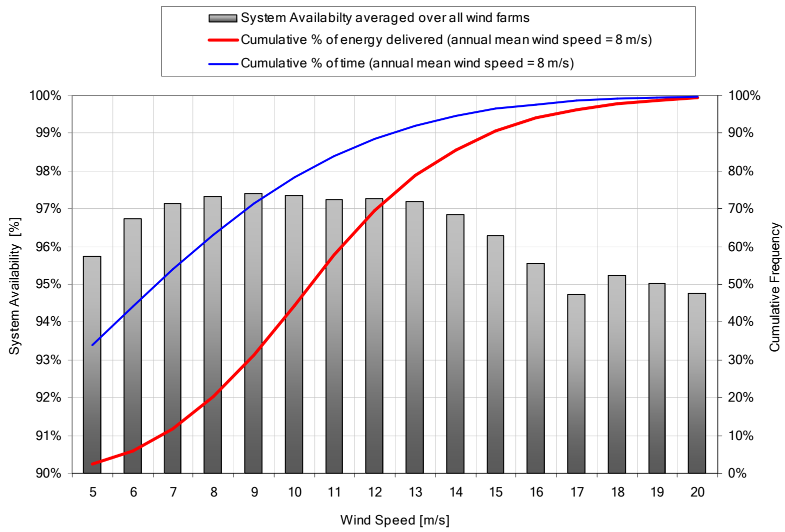

Figure 4 Availability versus wind speed

On the x-axis is wind speed measured by the nacelle mounted anemometers and on the y-axis is System Availability. The bars show the average of all wind farm results for each wind speed bin. The solid blue line shows the cumulative % of time in one year spent at or below a given wind speed for a site with a nominal annual mean wind speed of 8 m/s. The solid red line shows the cumulative amount of nominally energy delivered in one year.

It is immediately obvious that the availability is relatively constant between 7 and 14 m/s and it is in this wind speed range that the majority of energy is delivered.

At high winds, above 15 m/s, high load faults may be more common causing a notable reduction in availability. Such faults may be associated with vibration protection alarms, pitch mechanism malfunction or generator over-heating. As well as an increased likelihood of these faults occurring at high winds, turbine repair time is often prolonged due to restrictions associated with safe access to the site and turbines.

Conversely, at lower winds, below 7 m/s the availability also reduces. This is due to down-time associated with non-urgent maintenance activities that are to some extent scheduled for calm periods. For instance, annual servicing can be scheduled for lower wind summer months and on a more macro level turbines may be shut down during calmer periods forecasted on a daily basis.

In order to assess what this means in terms of energy losses, it is important to consider the frequency of occurrence of wind speeds in each of these bins. The significance of the lower availability at high winds is shown to be less than Figure 4 may initially indicate. In energy production terms, the impact of lower availability at high wind speed is in fact balanced with lower availability at lower wind speeds. For the subset of wind farms considered here, the overall result is that there is no significant overall bias in the wind speed versus availability relationship and for these wind farms a 1% loss of energy resulting from 1% downtime seems sensible. This is a reasonable assumption that can be made on a new project.

However, it is imperative that availability risks must also be considered on an individual project basis. One striking example of where an external issue has caused an exception to the above trend is in a region of Texas where there is a high penetration of wind power. During high wind periods, when wind power outstrips demand on a relatively weak grid, the utility company enforces wind farm projects to shutdown. This external factor leads to a dramatic correlation between reduced availability and high wind speeds.

Other examples of potential issues that may impact the relationship between availability and high wind speed are:

- Severe climate issues, including icing issues;
- Severe systematic turbine faults associated with high load;
- Wind sector management where downtime is enforced in particular sectors to minimise noise or other external impact.

All of these issues (and possibly others that are not in this list) require review and potential factoring in, where relevant, on a project by project basis.

Conclusion and Discussion

When investing in a modern wind farm development, it is generally considered appropriate to expect 97 % availability averaged over the life-time of the project, typically 20 years. The results of this study provide confidence that, as wind farms reach maturity and teething issues are resolved, it is reasonable to expect 97 % availability on average.

It can be expected that from year to year, availability will vary above and below 97 %. The distribution of annual availability demonstrates that the number of occurrences of annual availability levels of less than 80% on a modern wind farm is relatively low. Such low availability may be caused by external factors, for instance utility enforced downtime, as well as turbine issues such as large component serial defects including gearboxes and blades.

It is useful to consider how these risks can be mitigated. Minimising the turbine availability risk is possible through procurement of a turbine availability warranty associated with an operation and maintenance agreement. This is typical in the first years of operation of the project. Some manufacturers will provide longer term agreements, up to 12 years. Some owners have negotiated availability warranties that actively encourage the performance of maintenance in low wind periods. A simple approach is to discount all planned outages that occur when wind speed is less than 4 m/s from the warranty availability calculation.

Availability risks associated with environmental conditions should also be considered on a regional or individual wind farm basis. For instance, icing can impact the ability of the turbines to operate efficiently as well as causing accessibility problems. At high wind speed sites, repairs to components such as blades can be delayed causing high turbine downtime. It is therefore very important to establish the impact of environmental conditions as this type of down-time is often a risk taken on by the wind farm owner.

Increasingly, it is industry practice for the turbine manufacturer to negotiate an allowance of between 48 and 120 hours a year for ‘routine maintenance’ of the turbines. This includes such activities as oil changes, greasing and bolt tightening. In some contracts, work associated with “retrofits” is also excused. Time taken carrying out these activities up to the allowance limit does not count against Turbine Availability. The impact of this allowance on the warranted availability should be fully understood.

The trends presented from the historical wind farm data show that, on the whole, availability is relatively insensitive to turbine size and wind farm size once teething issues have been resolved, usually in the first year or two of operation. In some respects the lower availability from the larger turbines in the first year or two of operation is to be expected, as the turbines are generally more complex designs and therefore teething issues may be considered more likely. The risk of a lower availability from teething issues may to some extent be mitigated through the turbine warranty.

Many owners and operators have shown concern that availability may be lower at high wind speeds and that the true energy loss is not reflected in the availability figures seen in operating reports; in effect, the lost energy is not recoverable. In an attempt to address this concern, the relationship between availability and high winds has been investigated. On balance, it has been demonstrated that it is reasonable to assume on average, for a wind farm not impacted by unusual external constraints, that 1% of downtime will generally result in 1% of energy loss in the long term.

The risk of lost production, and hence lost revenue, as a result of low availability should be clearly understood on a project by project basis. This is typically done through an independent technical due diligence assessment prior to investment or purchase.

There are few modern wind farms that have operated in excess of 10 years and therefore no strong conclusions are drawn for availability beyond this. However, it is considered prudent to allocate increased operation and maintenance budgets after operational year 10 and again after operational year 15 to minimise the impact of increased probability of component failure as the end of the turbine design life is approached.

The conclusions drawn from reviewing the trends presented in this paper are to be taken in the context of the wind farm data included in the database. Therefore, the following points are to be considered:

- The statistics are collected from a geographically diverse population of wind farms and therefore the equivalent trends may vary from region to region;
- The database contains statistics from all turbine manufacturers and turbine types for which data were obtained. Some turbine types may be considered ‘unproven’ and availability levels may vary between turbine manufacturers;
- The database has a high proportion of availability statistics for the previous generation of sub-1MW turbines. Indeed the majority of wind farms included that have operated for over 5 years are sub-1MW turbines;
- The smallest turbine size represented in the database is rated at 300 kW, the largest is rated at 3MW. The wind farm sizes vary from only a few turbines to wind farms consisting of over 100 turbines. No weighting is applied for turbine or wind farm size;
- For a subset of wind farms where only Turbine Availability has been provided a further adjustment factor of 99.5% has been applied to convert to an estimate of wind farm System Availability.

Having taken these points into consideration, the trends and observations presented in this paper provide a valuable instrument which, if used appropriately, can help gain an understanding of the risks associated with availability throughout the lifecycle of a modern wind farm project.