Never a breeze

01/05/2005

While many aspects of performance risk are germane to most forms of power generation, some take on new and fundamentally different attributes in the context of wind power projects. For example, wind-turbine performance is extremely sensitive to changes in wind speed and direction; electrical output from a wind turbine-generator (WTG) is proportional to the cube of the prevailing wind speed, meaning that a doubling of wind speed results in an eight-fold increase in electrical output.

As a result, wind availability remains the biggest risk to wind project viability. And because – hedging aside – developers cannot enter into contractual commitments to cover this particular risk, reliable predictions of wind speed and direction are vital to assessing returns on a prospective wind project. Assuming that adequate wind is available, another major performance risk lies in the ability of the wind farm to harness that wind.

Wind PPAs

In wind power purchase agreements, the payment structure typically provides for payment based exclusively on an energy charge, although it invariably includes a corresponding obligation on the power purchaser to buy all the electricity available from the wind farm so the demand risk remains with the power purchaser.

This "energy only" payment structure makes wind projects particularly sensitive to reductions in available capacity since any loss of capacity is immediately and directly manifest in the metered quantity of energy delivered to the customer. How, then, to detect and protect against losses in available capacity? Although the easy solution for developers and sponsors is always to push such risks onto creditworthy equipment suppliers, installers, and operators, doing so is not always possible or straightforward.

Performance testing strategies

Available capacity risk at a wind farm needs to be addressed at two key stages during the life of the project: during completion testing as the plant is commissioned and placed into service, and during the operational period thereafter.

Typically, at completion of construction, the WTG manufacturers and installers will be required to demonstrate actual installed capacity consistent with the parties' expectations. This is relatively straightforward with conventional power plants where capacity and efficiency measurement techniques, equipment and standards are well established. However it is more complicated with wind power plants, where the first problem stems from the fact that wind farms invariably consist of several – and perhaps a great many – individual WTGs.

In contrast to the one or two individual generators in most conventional power plants, the prospect of testing each individual WTG is both time consuming and expensive. The alternatives? The simplest approach might be to measure a sampling of WTGs and extrapolate the results across the remaining units, but several problems arise here, including how to select the units to measure, and what to do about the risk of failing to identify underperforming units.

It may be tempting to consider simply measuring the total power generated by the wind farm and averaging the result across all turbines, an approach that has the benefit of capturing not only the collective output of the individual WTGs, but (assuming the aggregate power is measured at the electrical connection to the transmission and distribution grid) including the relative contribution of the balance of plant electrical equipment (e.g. transformers, switchgear) in the performance assessment.

This approach is expeditious, and since it measures the net electrical output of the plant (which determines revenues) arguably the most meaningful, however it is not without shortcomings: for example, the contractor will invariably include margins in the individual WTG performance guarantees, and when results are averaged, the bulk of the properly performing units may disguise one or more significantly underperforming units.

In order to avoid such a situation, any approach to performance verification that looks at the wind farm as a whole would also need to be supplemented by additional performance criteria in respect of individual WTGs.

Performance testing techniques and standards

Whether the developer opts simply to measure the net output of the wind farm or prefers instead to bear the expense of verifying performance at each individual WTG, this choice is not the end of the testing story since additional issues arise in the actual direct measurement of performance.

With some exceptions, conventional power plants are typically sized to operate at more or less peak load, and output and efficiency are therefore measured on that basis. (Conventional power plant efficiency does vary with output, and may be measured and guaranteed across a range of output, but it is generally efficiency at peak output that is of greatest interest.) As mentioned previously, WTG output is a function of wind speed, and since wind speed varies considerably during operation, in contrast to conventional plants, a WTG is rated – and performance guarantees should be provided – based not merely on maximum output, but rather on a curve reflecting electrical power output as a function of wind speed.

In order to truly understand whether a WTG is performing properly, the actual performance curve must be measured and compared to the theoretical performance reflected in a power curve provided by the WTG manufacturer. Establishing the actual power curve requires simultaneously monitoring both the prevailing wind and the respective WTG's electrical output over a period of time and a range of wind speeds sufficient to establish a statistically meaningful database of wind speeds and corresponding power levels.

Power output is comparatively easy to measure; assuming the parties have agreed to measure each unit individually, WTGs may already be fitted with individual power output meters as part of the plant data acquisition and control (SCADA) system, or if those meters are not sufficiently accurate for the purpose, temporary meters can readily be installed at individual WTGs as they are tested.

If the parties have elected to monitor performance based on an aggregate output of the entire wind farm, electrical output can simply be measured at the interconnection to the power distribution grid, and indeed accurate meters will likely already have been installed for billing purposes under the power purchase agreement. The real challenge lies in measuring the wind.

IEC standards

The International Electrotechnical Commission (IEC) publishes numerous standards related to wind turbine-generator design, safety, monitoring and testing, including standard IEC 61400-12 – Wind Turbine Power Performance Testing. Published in 1998, this IEC standard attempts to establish a uniform methodology for measuring, analyzing and reporting wind turbine-generator performance by measuring electrical power output as a function of wind speed for individual WTGs.

Testing under the 61400-12 standard involves, in short, erecting a meteorological mast (met mast) equipped with wind speed and direction measuring instruments, and recording wind speed simultaneously with the electrical output of the WTG being tested. Because it is not possible to measure directly the actual wind speed realized at the WTG blades, the met mast is mounted as close as possible without disturbing the natural air flow at the WTG, and a calibration procedure is applied to accommodate for differences due to wind flow distortion between the met mast and WTG blades.

The role of IEC 61400-12 in WTG performance testing is analogous to that of the ASME and ASA standards that have long formed the basis for performance testing of conventional thermal plants, however the IEC 61400-12 standard is relatively new and still in its first edition, and is not nearly so comprehensive or thoroughly developed as the latter.

Indeed, although 61400-12 expressly contemplates that it be employed by wind turbine manufacturers and purchasers alike in establishing WTG performance requirements, it also cautions that the site calibration procedures involved in in-situ wind speed measurement are relatively new, and that "there is no substantial evidence that it can provide accurate results for all sites, especially sites in complex terrain", where uncertainties could be as high as "10% to 15% in standard deviation"#.1

These warnings have been borne out in the standard's application, where local conditions such as inclement weather and, even more so, irregular topography can present real problems in the application of IEC 61400-12. Whereas measuring wind speed at a wind farm situated in a predominantly flat area may prove relatively straight-forward and provide for reasonably consistent and accurate test results, areas with difficult terrain – where the best wind regimes are often found – and the presence of trees, gullies, outcroppings, or other natural obstacles (which may produce considerable localized variations in wind speed and direction) have proven much more problematic.

Problems

Where erratic wind flow characteristics at the site produce inconsistent data on wind speed, the resulting data scatter – the randomness of recurring data points within a certain range, which is represented by "error bars" in the measured power curve – introduces potentially significant uncertainty in the test results.

In 2000, the US Department of Energy (DOE), the Electric Power Research Institute (EPRI), and several utilities completed and reported on their joint evaluation of the performance and other attributes of new wind turbine designs and equipment in a commercial utility environment. Part of the purpose of their testing program was to gather experience with IEC 61400-12 by conducting all measurements and testing in accordance with the newly published standard.

The results of their efforts, published as "Power Performance Testing Activities in the DOE-EPRI Turbine Verification Program"2# illustrated, among other things, the sensitivity of test results to subtle changes in physical parameters, including WTG configuration during the test period, where adjustments to WTG position to reduce blade oscillations during testing produced variations in power measurement of as much as 15% or more at certain points on the power curve.

The study also experienced significant difficulties with uncertainty in measuring the wind speed, concluding that wind speed measurements were a significant – in their case the largest – source of error in measuring the actual performance of a WTG, a condition that could only be improved with a better understanding of wind flow distortion between the meteorological mast and the test turbine.

Indeed, some of the test results were simply not believable: in one test, owing to adverse weather conditions (ice and lightning activity) and complex terrain, uncertainties in wind measurement resulted in such extreme errors that even the data points within the lower limits of the error bars indicated a degree of aerodynamic efficiency in the test turbine in excess of that theoretically possible for a WTG with a hypothetically ideal rotor.

After exhaustively examining the raw test data and eliminating the possibility of problems with the sensors, data acquisition system, and data processing techniques, the testing team concluded that the errors must have resulted from problems in the site calibration procedure. It was apparent from their efforts that the IEC standard can be difficult to apply in highly complex terrain, and that difficulties in accurately measuring wind speeds have the potential to produce unacceptably high levels of uncertainty in performance test results.

Pending new IEC standards

Although the IEC feels that the matter of testing individual wind turbines on straight-forward, uninterrupted terrain is fairly well covered by the current know-how, the working group responsible for developing the IEC standards recognizes that much work remains to be done in reducing the uncertainties inherent in testing wind turbines under the influences of complex terrain, a source of particular frustration for IEC members from countries such as Greece and Italy, where complex terrain is practically endemic to wind project development.

In an effort to improve its wind turbine performance verification standards, the IEC has been working to develop three new standards related specifically to the performance testing of wind power generation equipment which will replace the 61400-12 standard. The IEC has just recently completed internal deliberations over the first of those three replacement standards, IEC 61400-121 entitled "Power Performance Measurements of Grid Connected Wind Turbines", publication of which is expected some time later this year.

A direct successor to the original 61400-12 standard, this new standard will similarly address performance testing of individual in-situ WTGs, although unlike its predecessor, it will only attempt to address installations with relatively simple site configurations, where testing can be conducted under well defined conditions and the results should not be subject to the effects of measurement complexities or the introduction of uncertainties associated with complex terrain. In that regard, 61400-121 will look much like the original 61400-12 standard, although some minor changes can be expected.

Verifying individual wind turbine performance under the effects of external influences such as complex terrain will fall to the second of the proposed new IEC standards, 61400-122, tentatively titled "Verification of Power Performance of Individual Wind Turbines". The IEC technical committee hopes that this new standard will improve on some of the shortcomings in the original 61400-12 standard vis-à-vis uncertainties associated with measuring the prevailing wind in complex terrain situations. Standard 61400-122 is still under development, with preparations currently being made to circulate a draft for comment to the full membership of the technical committee responsible for its development. It could be some time, however, before a final version is ready for public consumption.

In response to the demand for a uniform approach to performance verification of entire wind farms, the third effort pending from the IEC is their proposed new standard 61400-123, tentatively titled "Power Performance Measurements of Wind Farms". This new standard, also currently being prepared for distribution and review by the full technical committee membership, will consider the performance of entire wind farms as opposed to individual WTGs, and will hopefully provide a meaningful and cost effective solution to the impracticality and expense of trying to measure and aggregate the performance of each WTG in a wind farm.

Although relatively little is known about the details of IEC 61400-123 at this time, the IEC has indicated that it will measure wind farm performance in relation to a met mast, meaning presumably one or more meteorological masts located at the site and somehow used to derive a measure of actual wind speed across each of the WTGs at the site. What remains to be seen is how many masts will be involved, and how the IEC will address the potential for localized wind speed differences between the met mast(s) and all WTGs in a wind farm, especially where large numbers of WTGs are involved and are spread across physically large areas or over complex terrain. Foreshadowing the answer to that question, the IEC technical committee has acknowledged that their proposed approach is not a panacea, and that absolute measurement of the performance of entire wind farms is simply not practicable at this time.

Standards alone are not enough

For developers and sponsors, it is always tempting to try and push unwanted risks onto creditworthy suppliers, installers, and O&M contractors. However, that cannot always be done, and not without additional cost. Striking the proper balance between assumption and assignment of risks requires a thorough understanding of the mechanisms in play and the options available, as well as a careful assessment of the relative costs and benefits of each.

While the IEC has developed an important and helpful basis for verifying performance at individual WTGs, and with all due respect for their efforts, we are still at the vanguard in the development and application of wind farm testing techniques. From a contractual standpoint, it is not enough for developers to simply rely on a reference to the relevant IEC standards in their construction and O&M agreements and hope for the best. To begin, at least until such time as the proposed new IEC 61400-123 standard for performance verification of entire wind farms is published and proven, and assuming the IEC's proposed approach is appropriate and finds favour in every instance, it will remain necessary for wind project developers and their contractors to first discuss and develop a balanced and comprehensive strategy for WTG and wind farm performance verification, and then clearly incorporate that strategy into the relevant contract documents.

With such a strategy in hand, developers and their contractors may then wish to look to the IEC standards to help define the specific techniques that will be applied in the measurement, analysis and reporting of test data, but should do so with a full understanding of the express purpose and limitations of those standards, and should apply them accordingly. Otherwise, the parties cannot be sure that their respective rights and obligations in relation to WTG performance have been clearly delineated, or that important questions related to the actual measurement and reporting of WTG performance – such as which party will benefit from measurement uncertainties – have been properly addressed.

In many instances, and particularly with respect to large wind farms and those located offshore or in difficult to access areas, measuring performance at individual WTGs will prove impractical, and the cost and time involved will pressure developers to opt instead for testing the entire wind farm and demanding guarantees in respect of aggregate wind farm output.

Indeed, this may be the most sensible approach, provided it is supplemented with a second tier of individual guarantees in respect of each WTG designed to identify and provide redress for significant or obvious underperformance at individual units. The latter would benefit from the inclusion of instantaneous remote metering at each WTG, and the respective contracts should include an owner right to require individual inspection and testing of any suspect WTGs, the additional costs of which should be borne by the owner or the contractor depending on whether the WTG in question is found to be operating within the limits imposed by the individual WTG guarantees.

Several of the larger wind turbine manufacturers will, in addition to providing turnkey solutions for wind farm installation, also take on responsibility for the long-term operation and maintenance of the facility, and are arguably best suited for the job. Assuming a satisfactory pricing agreement can be reached, dealing with a single entity on all matters related to WTG installation, operation and maintenance has obvious advantages, although separate construction and O&M contracts will probably still be required, in which case it remains important to ensure that the delineation of responsibilities in each contract is clear, and that there are no gaps between the agreements.

Shaun J. Beaton is a professional engineer and attorney based in Paris. Mr. Beaton specializes in energy and infrastructure project development and construction, and has represented developers, contractors, sponsors and lenders in relation to projects in North and South America, Europe, Africa and the Middle East. He can be reached at shaun.beaton@wanadoo.fr.

Footnotes
1 IEC 61400-12, "Wind Turbine Power Performance Testing", Ed. 1, 1998.
2 The researchers were John VandenBosche, Tim McCoy, and Heather Rhoads of Global Energy Concepts, LLC of Kirkland, Washington.