WINDTECH INTERNATIONAL

June 2018 | Volume 14 | No. 4

Operational Data Analysis with a Cloud-Based Wake Model

Joining Up Observation and Simulation of Wind Farms

Operational Data Analysis with a Cloud-Based Wake Model

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When assessing the monthly performance of wind farms post-construction, uncertainty in assumed wake losses contributes a substantial proportion of uncertainty in the production assessment. The operational data analysis software of Lindahl now integrates the cloud-based wake model, WakeBlaster, providing a simple interface for simulating wake climate over the project operating history of a wind farm.

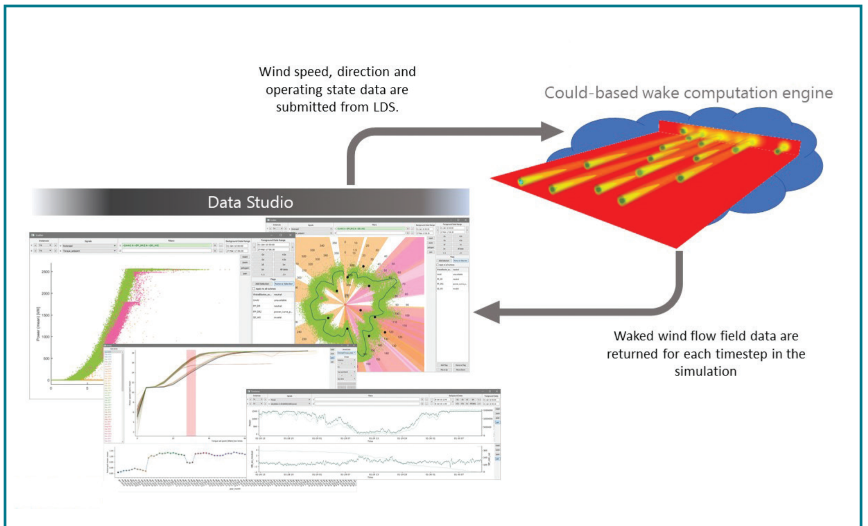

Figure 1. The Integrated Approach. The Data Studio submits environmental and operating state data to WakeBlaster. The wind farm is simulated and the waked flow field at each turbine and timestep are returned to the data studio for further processing.

Why are Monthly Wake Losses Hard to Account for?

Traditionally, wake loss estimates for wind farms have been calculated prior to construction of the wind farm using statistical representations of the typical environmental conditions at a site, such as directional wind speed distributions. This generally results in single average annual wake loss expectations for each wind turbine location. Wake losses for a given short operating period are, on the other hand, highly dependent on the environmental conditions at that point in time, as well as on the operating state and mode of each wind turbine.

Accurate modelling of wake losses for short operating periods therefore requires more granular input data which closely represent actual conditions at discrete points in time. The traditional wake simulation systems widely deployed in the industry in the pre-construction phase are not designed to deal with such a rich input dataset in an effective manner and, consequently, the industry has not been able to take this complexity into account.

Wind Farm Flow Simulation

WakeBlaster is a cloud-based wake model using a three-dimensional (3D) Reynolds-averaged Navier–Stokes solver with eddy viscosity turbulence closure. It simulates waked flow in the wind farm and calculates wake factors of both wind speed and power on a flow-case by flow-case basis where each flow case represents 10 minutes of steady-state wind conditions.

WakeBlaster has two significant advantages over the traditional wake models used for energy production assessments. Firstly, it uses a 3D wake model, which enables a more accurate modelling of multiple wake cases and boundary layer interaction. Secondly, it is based on the cloud with an open application programming interface, which allows flexible and powerful use and easy integration into external tools and software.

Operational Data Processing

Lindahl is providing a data exploration studio designed for expert wind turbine operations analysts. Unlike the online data management and monitoring systems that have surged over recent years, as much in popularity as in variety, this system is built with the technical analysts and data scientists in mind.

By wrapping data handling, visualisation, model development and calculations into a single package, wind farm performance analysts can explore every detail of their data. The system easily handles the vast quantities of data generated by large modern wind farms, providing near instantaneous access to any data signal for any wind turbine in even the largest wind projects, for datasets spanning decades in duration.

The advanced data handling system coupled with a fluid and rapid graphical interface allows the user to quality assure the input data, to diagnose and classify operational issues, and to derive the insight required to automate the state detection and subsequent performance classification.

Integrated Approach

Following data quality assurance and performance classification, the historical operating data are submitted to the WakeBlaster cloud platform, where new virtual simulation environments are created dynamically, as required. For each time sample received, WakeBlaster uses its proprietary algorithms to build a representation of the wind climate across the wind farm site – for each time step. Critically, the algorithms are not dependent on receiving data from a particular meteorological mast or having wake-free data; the algorithms are designed to build a representation of the ambient flow, based on aggregate data from all wind turbines, meteorological masts, and reanalysis datasets.

The wind farm simulations are initiated using the recreated ambient flow conditions. WakeBlaster provides an output of power, wind speed, wake effect, and some additional parameters for each turbine and time step, and these are pulled back to the data studio as new data signals. It is then possible to directly compare simulated and observed signals of power and wind speed, and then derive information about the project wake state for any period of time.

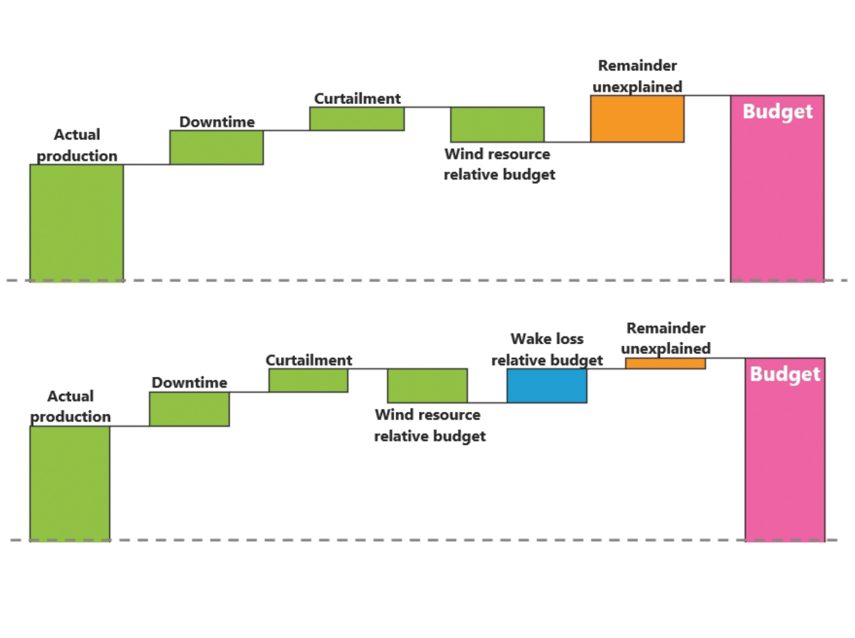

Figure 2. Two example monthly budget analyses in which actual production is compared with the budgeted production considering various monthly variable losses such as downtime, curtailment and resource. Top: The wake losses are simply assumed pro rata, creating an uncertainty which ultimately results in an unexplained remainder. Bottom: Wake losses are accurately predicted for the specific month, resulting in a small unexplained remainder

Application Cases

Having detailed insight into the wake climate at a wind farm site over the operating history of a wind project opens up opportunities for many stakeholders in the wind industry.

Post-Construction Yield Assessments

The financial benefit of refinancing a wind project on the basis of a post-construction yield assessment is well appreciated in the industry. The benefits stem from the reduction in uncertainty associated with such a prediction, compared with a pre-construction assessment. The prospect of further reductions in uncertainty, and perhaps more importantly, the prospect of adopting the post-construction prediction earlier in a project's operating life, provide opportunities for increasing a project's internal rate of return.

Classic post-construction yield assessments rely on establishing correlations between an idealised production time-series for the project to a long-term reference dataset. Correlations are typically undertaken at a monthly time resolution. At higher resolution, for example fortnightly or weekly, non-linearities elevate the required data volume. At still higher resolution, for example daily, the variability in wake climate typically causes the correlation to break down. By incorporating a detailed simulation of the waked flow, daily wake losses can easily be quantified and accounted for in the production time-series, allowing robust non-linear correlations to be established at daily (or even shorter) time step resolution, facilitating early life post-construction assessments and reducing uncertainties in classical assessments, which use monthly correlations.

Operational Monitoring

Wind project stakeholders are understandably keen to keep a close eye on the operational and financial performance of their assets. As part of ongoing monitoring, reports are typically issued by the operator on a monthly basis. These attempt to summarise information on production, energy losses due to downtime and curtailments, and the impact of resource variability. The information is then compared with a production budget in order to derive indicators for how the project is performing, relative to expectations.

Large deviations between the actual production and quantified losses, relative to budget expectations, are generally put down to large uncertainties in resource availability and to wake losses. Deviations on a monthly basis in the region of 10% are not uncommon, precluding early detection of prominent issues. By quantifying wake losses, a significant contributor to overall uncertainty is removed, thus improving the accuracy of the production balancing exercise and enabling earlier detection of operational or budget issues.

Figure 1 shows two monthly production analyses compared with the budgeted production: a) a budget analysis without knowledge of specific monthly wake losses, leaving a significant proportion of the budget mismatch unexplained, compared with b) a budget analysis with an accurate analysis of wake losses included, thus leaving only a small amount of the budget unexplained.

Furthermore, a poor calculation of the monthly wake losses can lead to much uncertainty when looking for turbine underperformance. Figure 2 shows an example monthly per-turbine production analysis. Without knowledge of wake losses, it is not clear whether any of the turbines are underperforming. However, once an accurate calculation of observed wake losses is made, it becomes clear that turbine 2 is underperforming as it only had low wake losses in that month; thus, the losses can be attributed either to underperformance or to an overly optimistic budget.

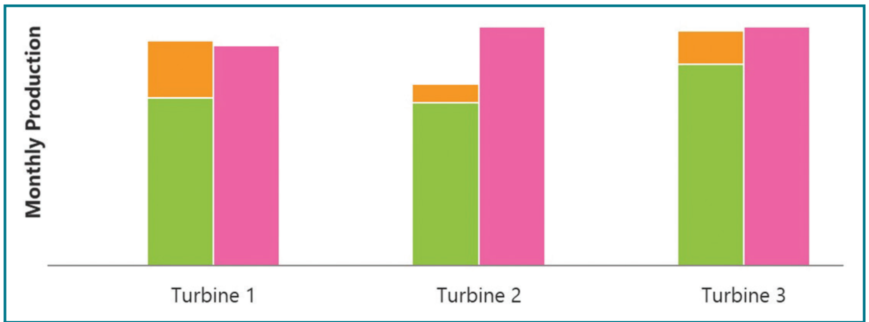

Figure 3. A single month's production broken down by turbine. An accurate per-turbine prediction of wake losses indicates lower wake losses on turbine 2 for this month, which results in an unexplained underperformance of the turbine. Without an accurate prediction of wake losses, it would have been more difficult to detect this underperformance

Conclusion

Accounting for wake losses has been a major source of uncertainty in processing post-construction SCADA data for lifetime energy production assessments and operational monitoring. A lack of processed information for the wakes leads to significant uncertainty and delays in the determination of turbine underperformance and energy budget issues. The integration of WakeBlaster provides users of SIFT with an integrated solution for quantifying wake losses, thereby reducing post-construction uncertainties and improving the ongoing monitoring and optimisation of operating projects. ■

Staffan Lindahl has over a decade of experience in the analysis and optimisation of operating wind energy plants. He founded Lindahl in 2017 with a vision of sharing experience, knowledge, methods and software, to support project stakeholders in maximising asset value through optimisation, and thereby contributing to a better, cleaner and more sustainable future.

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