Engineering Simulation Technology Helps to Ensure Success of Wind Energy Projects

a report by
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In order to meet the world's energy demands in a sustainable manner, engineers need to deliver robust innovative technology. For 30 years, CD-adapco has enabled energy engineers to do just that in the 'traditional' energy sectors. Now we're routinely applying our technology and expertise in the renewable energy sector as well.

Computational fluid dynamics (CFD) is an engineering simulation technique that simulates fluid flow phenomena using computer technology. CFD can be used to simultaneously simulate the efficiency of a wind turbine while calculating the structural loading on it.

A wind turbine is essentially a very large, inverse fan. Instead of using electricity to produce a small breeze, the wind pressure acting on the blades of the turbine turns a rotor which, via a gearing mechanism, drives an electricity generator. The challenge for wind turbine designers is to extract the maximum amount of energy, in the widest range of conditions, at the least cost.

Wind Farm Prospecting

One of the largest challenges faced by operators of wind turbine technology is deciding exactly where to locate the wind turbines in order to maximise energy output while protecting asset durability (wind turbine gear boxes are vulnerable to extreme gustiness events). Placing turbines in regions with relatively clean airflow significantly increases their power output and longevity.

STAR-CCM+ has been used to simulate the airflow over a potential site and turbine configurations to enable wind farm developers to visualise complex wind patterns, identify areas of high wind speeds or turbulence and optimise turbine positioning. The simulation technology, which is already being used by a leading turbine manufacturer, addresses two of the biggest challenges in prospecting: the prediction of wind power density across complex terrain and the identification of local flow features likely to negatively influence asset durability.

CD-adapco has developed a unique automated process, through which large areas of terrain can be evaluated, with little or no manual input from the operator. The process is based around STAR-CCM+, CD-adapco's flagship simulation tool, which automates every part of the wind park simulation – from importing the terrain geometry to producing a final report that identifies the suitability of a particular area of land for wind turbine installation.

Dennis Nagy, CD-adapco's Vice President for the Energy Industry, explains: 'Previously, numerical simulation for wind-park prospecting was rightly criticised because it either oversimplified the physics or was too complex and time consuming to deploy on a realistic scale – often requiring the integration of many different software modules and simulation times in excess of two weeks. In this respect, STAR-CCM+ is paradigm changing – allowing large areas of terrain to be analysed for 12 different wind directions in less than three hours, and with little or no manual input from the operator.'

As well as evaluating the wind power density, the report produced also identifies local 3D flow features such as wind-shear, wind-veer and local gustiness that are likely to have a negative impact on the durability of the wind turbine gearbox.

Aerodynamics and Structural Loading

Obviously no wind turbine is able to extract all the energy from the wind (operating at a theoretical 100% efficiency); if one did so the air behind the turbine would be perfectly still, even in the windiest conditions, preventing new air from passing through the blades of the turbine.

In order to maximise their efficiency, most current wind turbines were designed using extensive experimental model testing. Although experimental analysis provides considerable insight into the performance of a particular design, physical prototypes are expensive and time consuming to construct.

Unlike testing of physical prototypes, CFD simulations are typically carried out at full scale (the computer model has the same dimensions as the actual production wind turbine rather than those of a smaller experimental model). This has the considerable advantage that results can be interpreted directly and do not have to undergo scaling, a process that can introduce a significant uncertainty, especially for transient phenomena, such as the impact of an extreme gust event.

During the design of wind turbines, designers aim to simultaneously increase a turbine's power output over the full range of operating conditions, while improving durability. In a recent project, wind turbine design company RingWing used STAR-CCM+ to improve the design of their innovative shrouded turbine. The simulations provided detailed insight into the aerodynamics of the turbine as well as the force loading on it, enabling engineers to quantify the effect of design changes.

In a recent project, CD-adapco's engineering services team helped to demonstrate the feasibility of a revolutionary new wind-turbine concept using engineering simulation, giving its designers the confidence to invest in an full-scale prototype and ultimately to bring the design into successful commercial production.

The Windgiant turbine utilises revolutionary technology, in which wind flow is accelerated through a multibladed fan using a number of concentric aerodynamic shrouds. Compared with traditional three bladed turbine designs, the compact Windgiant turbine delivers a much higher energy per unit surface area and operates at much lower wind speeds (delivering energy at wind speeds as small as 1.5m/s). Combined with its ultralow noise energy production (less than 40dB (A) at 12m), the compact design of the Windgiant turbine means that it is suitable for installation in urban residential settings, as well as industrial environments. Currently available in 10kW and 20kW, Windgiant is developing a much larger hybrid-tower which delivers 2.5MW from a combination of wind and solar power.

'CD-adapco's engineering services team helped us to demonstrate that our concept was valid and allowed us to fine tune our design before investing in expensive physical prototypes,' said Gerhard Wieser, the designer and innovator behind the Windgiant project. 'Having successfully installed a number of Windgiant turbines, I am delighted to report that the devices' behaviour is as predicted by the simulations, with each device delivering plentiful supplies of low-cost electricity in complex urban environments.'

Upfront design investigation can have a big impact on a project's profitability. In another wind turbine design study, this time by the University di Udine, Italy, the business benefit of early understanding of designs, prior to prototyping, was recognised. Having compared various designs using STAR-CCM+, they gained a level of insight that had otherwise been unattainable.

University di Udine's Hans Grassmann states CFD's impact on the bottom line: 'If the simulations had been carried out before the prototype stage, millions of dollars could have been saved with obvious benefits to the project profitability and overall success.'

A combination of atmospheric boundary-layer inflow conditions and coupling to meteorological codes ensures accurate representation of the local weather conditions.

Extreme Conditions

As well as predicting how a given turbine design will perform under standard operating conditions, CD-adapco's CFD solutions are routinely used to understand how a turbine will react upon in extreme loading. This technology allows engineers to optimise the aerodynamic efficiency of the turbine and understand the range of conditions under which safe operation can be assured. The biggest advantage of CFD is that its rapid turn around time helps to break the dependence of wind turbine design on pre-existing design codes. Although design wind conditions are a useful starting condition for analysis, CFD simulation allows designers to more easily pursue multiple 'what if?' scenarios.

Once a CFD model for a turbine is set up, it is relatively simple to repeat the calculation for multiple loading scenarios. A further advantage is that, instead of being restricted to retrieving data from a few experimental monitoring probes, data is available at every point on the turbine, at every discrete time interval for which the simulation is performed. The simulation results can be viewed from any angle and the instantaneous forces acting on any part of the structure can be calculated. Data from CFD calculations can also be used to assist other types of analysis, for example, the forces acting on a turbine can be exported to a stress-analysis software package. In extreme cases, where fluid forces cause large deflections of turbine blades, the CFD simulation can be coupled directly with the stress analysis tool and both stress and fluid simulations can be performed simultaneously, each simulation feeding new boundary conditions to the other.

Offshore Wind Farms

Coping with higher wind-speeds, corrosion and wave impacts, the challenges of producing durable, cost-effective offshore wind farms are great, but far from insurmountable. One example where 3D flow simulation is having a significant impact is in modeling wave loading. The loading on the turbine-supporting structure can be determined for different wave heights, sea-states or wind speeds, at full-scale and without the expense of manufacturing prototypes or physical testing. Technology that's been routinely used in the marine industry for years is now being applied to reduce the impact of the harsh offshore environment on wind turbines. ■