Vestas®

PowerPlus™ case study

Aerodynamic Upgrades

Vortex Generators and Gurney Flaps deliver 1.7% annual energy production improvement across test sites

Wind. It means the world to us.™

Showcasing the **value** of Aerodynamic Upgrades

As part of the PowerPlus™ product suite, Aerodynamic Upgrades improve the aerodynamic performance of the rotor blades, boosting annual energy production (AEP) by up to 2%.

The technology consists of two add-ons, Vortex Generators and Gurney Flaps, which aid lift creation around the blades. This translates into a better aerodynamic performance during the turbine's partial load operation. The AEP improvement is therefore captured on the slope of the power curve, when the turbine operates below rated power.

The technologies are well-established in the industry and have been widely accepted as a performance enhancement. However, to get a stronger understanding of the actual improvement in energy output, Vestas has carried out rigourous validation across a number of different sites.

In this case study, you can read about the results of our validations, hear from a customer, and learn more about how the add-ons actually improve the aerodynamics.

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Turbine applicability Aerodynamic Upgrades

V82* V80-1.8/2.0MW* V90-1.8/2.0MW V90-3.0MW V100-1.8/2.0MW

*Only Vortex Generators

Swift, but strong

Rotor blades need to be as aerodynamic as possible, while at the same time be able to handle extreme loads when wind speeds rise. The root section especially requires a robust structure to withstand the force of the wind. Therefore, rotor blade design is always a compromise between the aerodynamic optimum and structural stability.

This, in turn, opens up for the opportunity to install specially designed add-ons to modify the airflow around the blades and make up for the aerodynamic losses caused by the design compromise.

5 sites around the world achieve **1.7% additional AEP**

Validating the actual performance gains from aerodynamic improvements is a challenging task. Vestas conducts rigourous validation on wind farms across the globe to accurately verify the effect of our Aerodynamic Upgrades.

Over a period of 12 months, five sites on two continents have been undergoing tests and validations to confirm the estimated production gains. The validated results from the test sites, representing four different turbine platforms, show an average AEP gain of 1.7%.

Confirmed estimates and proven versatility

The results confirm, and in all cases exceed, the AEP gains estimated prior to installation. Vestas uses state-of-the-art tools to provide gain estimates, which are generally conservative and usually outperformed by the validated production gains.

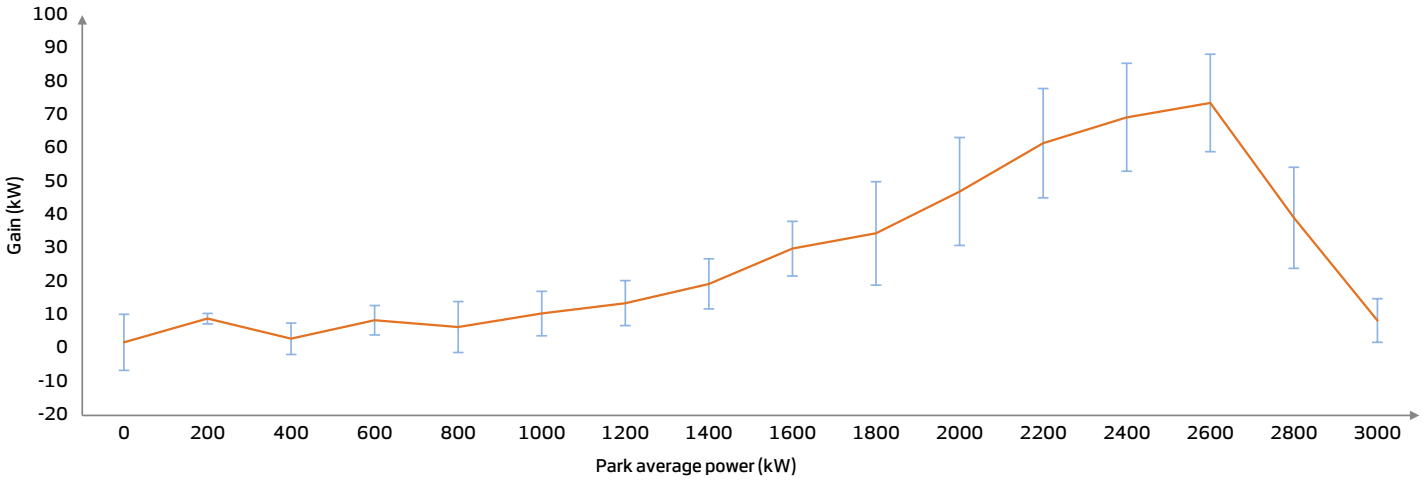
The field results also underline the broad applicability of Aerodynamic Upgrades across turbine platforms and in different wind conditions, with none of the sites gaining less than 1.1% additional AEP during the 12 months validation period. Ongoing monitoring of the sites will further refine the understanding of long-term performance of the upgrades.

Highlights

No. of sites	5
Avg. AEP gain	1.7%
Range of AEP gains	1.1-1.9%
Turbine platforms	V90-2.0MW®
	V100-1.8MW®
	V100-2.0MW®
	V90-3.0MW®
Location	North America, South Europe

Example of gain table from V90-3.0MW® site

Gained kW as function of average power output, incl. 95% confidence interval



ENGIE improves aerodynamic performance on V90-2.0MW fleet in Germany

To improve production across 5 sites in Germany, ENGIE has partnered with Vestas to enhance the aerodynamic performance of 24 V90-2.0MW turbines.

The decision to go with Vestas and the proven Aerodynamic Upgrades was an easy, says Rainer Röper, Senior Asset Manager at ENGIE.

"In the market of performance upgrades, aerodynamic enhancements are some of the more technologically proven solutions. Vestas' track record and the maturity of the Aerodynamic Upgrades gave us the confidence to invest."

Partnership based on mutual confidence

Confidence in the technology and the production gains meant that ENGIE chose to upgrade all the turbines from the beginning according to Rainer Röper.

"Together with Vestas, we established a common understanding of the gain potential. Vestas' estimation tool convinced us, so we decided to upgrade all our V90-turbines to maximise our returns."

The reasoning from ENGIE is exactly why Vestas carries out rigorous testing and validation of our upgrade features. When turbines are upgraded, owners and operators need to be confident that they are actually getting a return on their investment.

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Vestas' estimation tool convinced us, so we decided to upgrade all our V90-turbines to maximise our returns."

Rainer Röper
Sr. Asset Manager, ENGIE

However, site-specific validation is time-consuming and would limit installation to half the turbines in the first year, effectively reducing earnings. Vestas provides accurate estimates based on site-specific data, which coupled with the field test results, establish a solid foundation for investing in Aerodynamic Upgrades across entire parks.

"We trust the scientific proof behind it. And we expect our partner to deliver a realistic estimation of our return" says Rainer Röper.

Highlights

Sites	5
Turbines	24
Platform	V90-2.0MW®
Commisioned	2007-2009
Location	Germany
Aerodynamic Upgrade installation	2016

About **ENGIE**

ENGIE Deutschland offers a broad portfolio from efficient energy generation to technologies for planning, building and operating building infrastructures and energy systems, to energy procurement and optimisation of energy consumption.

With around 3 gigawatts of installed capacity, the ENGIE group is one of the largest operators of wind turbines in Europe and developing, constructing, operating and servicing wind farms. In Germany, ENGIE is operating 13 own wind farms as well as turbines for third parties.

How Aerodynamic Upgrades actually improve **production**

Improving aerodynamic efficiency of the rotor blades is a fundamental change to the turbines' ability to turn wind into power. This can be seen in the power formula for wind turbines:

$$P = \frac{1}{2} \times \rho \times V^3 \times A \times C_p$$

C_p, the power coefficient, represents the combined efficiency of the various turbine components to produce as much energy as possible from a given wind inflow. As the blades represent the direct interface between the turbine and the wind, their aerodynamic ability to capture the wind is essential to achieve a high power coefficient. For that reason, blades are designed to an aerodynamic optimum.

Optimising aerodynamically designed blades

However, blades are also exposed to a high amount of loads. Their final design is therefore a trade-off between aerodynamics and structural stability. A blade with ideal aerodynamics would crush under the loads from the wind. Specifically, the roots of the blades suffer from this trade-off, as the load exposure is highest there.

Consequently, the blades are not as aerodynamic as they could be. The objective with Aerodynamic Upgrades is to get closer to the aerodynamic optimum without exceeding the loads in the design envelope.

Aerodynamic Upgrades - Multibrand

In addition to the Vestas fleet, Vestas have installed Vortex Generators on more than 1,750 multibrand turbines. Vestas offers Vortex Generators for most major brands, including:

GE®
Gamesa®
Acciona®
Nordex®
Goldwind®
Mitusbishi®
Clipper®
Suzlon®

Recapture lost production with Vortex Generators

Early flow separation over the blade is the main cause for aerodynamic losses, and to prevent or delay flow separation, Vortex Generators are attached to the blade.

Vortex Generators are small fins that creates a vortex which re-energise the boundary layer to prevent early flow separation. The direct benefits are higher lift and reduced drag for the parts of the blade operating at a high angle-of-attack. The effect from these benefits depends on the state of the blade, both in terms of design and its condition, when the Vortex Generators are applied. As a result, the expected production gain differs from turbine to turbine.

Boost aerodynamics with Gurney Flaps

Installed at the trailing edge of the blade's root section, Gurney Flaps increase pressure on the pressure side, decrease pressure on the suction side, and attach a boundary layer air flow all the way to the trailing edge on the suction side of the blade.

As a result of the increased pressure on the lower surface ahead of the flap, the upper surface suction can be reduced while producing the same lift – improving the lift to drag ratio as the flap is appropriated in size to the boundary layer thickness.

The aerodynamic benefits of the Gurney Flaps are amplified by the Vortex Generators on the suction side.

Certified solutions and easy installation

Both the load impact analysis process and the individual turbine evaluation in Vestas SiteCheck® are certified by DNV-GL. These processes ensure that the additional loads are correctly analyed, and that they do not take the individual turbine out of its design envelope.

The add-ons can be installed by various methods, including platform or rope-access. Depending on method, installation can be as fast as 1 day per turbine.

Boost the effect with smart algorithms

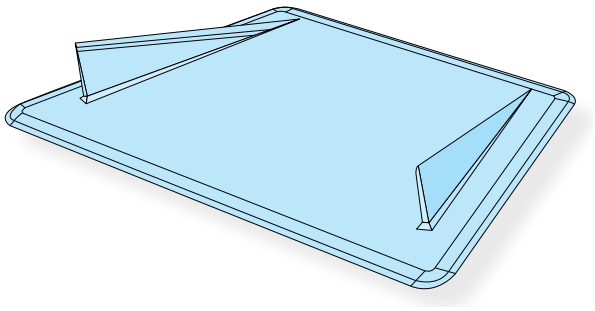
Combining the Aerodynamic Upgrades with Vestas' Power Performance Optimisation software upgrades allows the turbines to capture the full potential.

The smart software optimises the turbine production according to the changes in the airfoil caused by the Aerodynamic Upgrades. Vestas' field trials of the combined upgrade show a further production increase of 0.2-0.3%. Vestas always recommends to combine the two upgrades for an optimised output.

Lifelong durability

Aerodynamic Upgrades are installed with state-of-the-art adhesives from 3M, providing an expected lifetime of 20 years.

Having passed all tests applied by Vestas, the adhesives assure that the add-ons require no or minimal additional maintenance efforts. This helps establish a firm idea of the total costs and thereby a more certain business case for the upgrade investment.

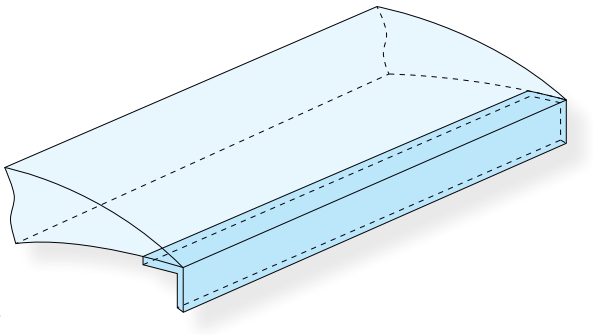


Vortex Generators

Strategically placed along the root of the blade, Vortex Generators prevent early wind flow separation in the root region by attaching the airflow to the blade. The recaptured airflow then creates additional lift, translating into higher production.

Gurney Flaps

Installed on the trailing edge of the blade, Gurney Flaps create lift by manipulating the pressure around the blade root and mid span.



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03/2019-EN