IMPROVING INSTEAD OF REPOWERING: A TECHNICAL, ECOLOGICAL AND ECONOMIC APPROACH

Henry Seifert[1)], Hergen Bolte[2)], Torsten Rotermund[2)], Jürgen Kröning[3)]

[1)] Hochschule Bremerhaven; Institute for Wind Energy fk-wind: An der Karlstadt 8, D - 27568 Bremerhaven,
+49 471 4823 547; hseifert@hs-bremerhaven.de
[2)] Energiekontor AG; Mary-Somerville-Straße 5, D - 28359 Bremen;
+49 421 3304 0; hergen.bolte@energiekontor.de
[3)] DEWI - OCC GmbH; Am Seedeich 9, D - 27472 Cuxhaven;
+49 4721 5088 11; j.kroening@dewi-occ.de

Summary

In the past some wind farms have been installed at sites not matching the appropriate wind class. Losses of annual energy production resulted and the economy of the parks was critical. In the wind farm analysed eleven one-Megawatt turbines operate since about 9 years with well recorded wind and operational statistics, showing lower production than expected in the planning phase. In previous studies methods to improve the turbines have been studied and have been analysed against its economic viability. Increasing the rotor diameter by two Meters promised the best economics. An extension of the blades at the tip was clearly recognised to be the best compromise for an effective realisation. No exact information about the aerodynamics and structures of the blades could be made available by the manufacturer. However, a certification of the modification had to be carried out in order to get a building permission and to guarantee the operator a safe operation with respect to the rest of the lifetime of the turbines. As a main result, the cut off wind speed was reduced to limit the critical loads even though enlarging the rotors diameter. Also the fatigue loads were analysed before and after the modification in terms of relative damage calculations. Finally, the blade tips for one turbine were built and assembled. Measurements of fatigue loads at the blade root as well as selected raw data for the evaluation of the natural frequencies have been carried out in order to compare two neighbouring turbines before and after the modification. Also a static load test of a test tip was successfully carried out in the workshop. The realised modification confirmed the expected production improvement by nearly eight per cent. Nor critical additional noise or loads and vibrations could be found compared to the non-modified turbines. The overall costs of the modification promised an economic and ecological improvement without repowering a whole wind farm and showed a return of investment of about three to four years for the improvement of a single turbine.

1. Introduction / Motivation

In the past some wind farms have been installed at sites not matching the appropriate wind classes. Reasons might be non-sufficient planning tools or lack of experience of the wind farm developers. Losses of annual energy production resulted and the economy of the parks sometimes moved towards critical regions. In order to increase the annual energy production of a wind farm or a single turbine, respectively, ways to improve the situation have been investigated and experimentally tested at such a site.

The project was ordered and initiated by the wind farm owner and operator, the company EnergieKontor AG. The research partner, responsible for the design, the load assumptions and the measurements was the University of Applied Sciences Bremerhaven. The tip parts have been constructed and assembled by the company L&L Rotorservice GmbH and the DEWI-OCC accompanied the project as the certification body.

To improve a given rotor efficiency needs a sound knowledge of the turbine design. In order to modify the blades to increase the energy production some properties of the whole turbine might change as well. These are for example the increase of ultimate and fatigue loads, the change of the natural frequencies of components, the control behaviour, the noise emission and finally the certification document of the type of turbine. Basis of the investigation is the equation of the power curve of a wind turbine which can be expressed as

(1) $P_{el} = \rho/2 \cdot v^3 \cdot c_p \cdot \eta \cdot A$ with

P_{el}	*electrical Power*
ρ	*air density*
v	*wind speed at hub height*
c_p	*rotor power coefficient*
η	*drive train and electrical efficiency*
A	*swept rotor area*

Not all the parameters can be modified for an optimisation of an existing turbine. According to the vertical wind profile the height of the tower can be increased to increase the wind speed. As the power growth with the cubic law, an increase of hub height will lead to an economic solution for a new installation. For low wind speed sites also a smaller Generator can be mounted featuring a higher efficiency at low wind speeds compared against a higher installation. Both methods are connected to high costs. Furthermore the rotor efficiency can be increased by optimizing the aerodynamics or the control strategy. Finally, the Rotor area can be enlarged by increasing the rotor diameter. All these modifications can be applied if a wind turbine is optimised for an inland site in its original design by the manufacturer. However, if the “wrong” turbine was chosen by the wind farm designer or the long term wind potential was predicted too optimistic most of the parameters shown above cannot be modified without spiralling the prices. Increasing the rotor diameter has been identified as the best choice which can be realised economically. Two methods can be applied: The use of an extender to be added between the hub and the blade root and an extension at the blade’s tip. For the first one the rotor blades have to be removed the second solution can be realised at the rotor directly.

In the analysed wind farm eleven one-Megawatt turbines designed for the IEC class II [1] or wind zone 3 according to the German Institute for building techniques (DIBt) [2], respectively, operate since 8 years at lower production than expected. Measurements of the wind conditions as well as monitoring the energy production since the erection of the wind farm showed, that the wind potential was far lower than originally predicted and the design of the turbines were optimised for higher wind zones.

2. Approach and principle design

In two preceding studies [3,4] several methods to improve the energy production of the turbines at the site have been carried out and have been analysed against its economic viability. Increasing the rotor diameter by two Meters showed the most promising results. However, a simple blade root extender proved to be a hard intervention in the structure and a too large increase of the deterministic loads on the turbines components. An extension of the blades at the tip promised to be the best compromise for an effective realisation. The starting point of the project was accompanied by the following obstacles: No exact information about the aerodynamics and structures of the blades could be made available from the manufacturer. A certification of the modification was necessary in order to get a building permission and to guarantee a safe operation with respect to the rest of the lifetime of the turbines. Furthermore, the blades should remain at the rotor for saving costs.

3. Load assumptions

One requirement of the certification body was a measurement of the blade root loads, the analysis of the natural frequencies and a static load test at the blade tip in order to validate the calculations and the modified load assumptions. Based on the geometry of a blade of the same type the outer airfoil section was identified. For the site specific certification the average wind speed at the site was analysed and the expected maximum wind speed was estimated as shown in Figure 1. The shut down at high wind speeds was proved to generate the critical load case for the ultimate loads at the rotor and the tower.

The technical approach was the following: The tip geometry was taken from an original blade tip, which was available at the project partner. With the known shape, twist and airfoil information of the blade - as mentioned before this was more or less a guess in some aspects - the aerodynamics have been simulated as close as possible to the original turbine. This could be checked by comparing the calculated versus the measured power curve. Showing acceptable results the geometry of the blade tip extension was designed. Figure 2 shows the drawing of the geometry and the principle fit to the original blade. In the lower part of Figure 2 the final tip at the turbine can be seen. The result of the simulation of the power curves in Figure 3 demonstrates the gain in the power curve especially in the area of partial power operation where the turbine operates most of the time at the specific site. As the turbine features an active stall control, the power control is not affected severely.

At that point of the design the improvement of the annual energy production versus annual average wind speed was calculated. In Figure 4 two methods are sketched. One curve shows the comparison of the two theoretical power curves. In a second version the relative change of the calculated power curves have been added to the measured power curve of the modified turbine. As can be seen the expected gain of energy production in the lower wind regimes are up to eight per cent.

The same proceeding has been applied to simulate the structure as close as possible to the original blade. This has been done to calculate the actual and the modified version for the determination of the new maximum blade tip deflection and the changed natural frequencies by adding an additional mass at the tip. In order not to exceed the ultimate loads in the critical load cases, the shut down criterion has been reduced accordingly. This is depicted in Figure 5. As the turbine was optimised for a low wind speed site, the frequency of occurrence of these high wind speeds are negligible for the energy production. Also the tip deflection at the emergency stops at the reduced high wind speeds could be proved to be in the old limits.

Additional masses of about 15 kg per blade had to be taken into account for the change of the natural frequencies. Using the Campbell diagram shown in Figure 6 possible resonances could be excluded. After checking the dimensioning load cases for the ultimate loads the possible changes of the fatigue loads were assumed. Here mostly the deterministic edgewise load of the blade had to be investigated. The number of rotor revolutions before and after the modification have been estimated and compared to an operation at the site for which the turbine was designed originally. By using a damage calculation it could be proved, that no additional damage was expected with the extension at the sit with lower wind speeds. For the verification the certification body asked for an accompanying measurement campaign of the blade root loads.

Summarising the method of the design, the cut off wind speed was reduced to limit the critical loads for the modified blades with extension. The fatigue loads were analysed before and after the modification in terms of damage calculations. Furthermore, the natural frequencies of the modified blade were checked.

A special method to assemble the new blade tip by using a lift was developed and tested with a separate outer blade part at the workshop. However, there is still an option to modify the blades during a regular revision in the workshop as well.

4. Verification of results

For the verification of the structural loads and the deflection of the tip extension a static load test of a tip in the workshop was successfully carried out. The calculated deflection at the maximum static load was proved by the test as shown in Figure 7. In opposite to the intended application of the tips at the site the prototypes have been mounted at the workshop as the blades were removed for a regular revision.

As agreed with the certification body a measurement campaign was defined and carried out at the wind farm. The measurements started long time before the application of the modification of the blades. For the measurement campaign two neighbouring turbines were selected and equipped with data logger at one of the blades each. The power production as well as the operational statistics such as rotor speed or operation mode respectively, technical availability, wind speed and wind direction at the nacelle, were recorded by the standard monitoring system of the wind farm. Ten minute averages were measured for the two turbines over a representative period. The aim of this campaign was to compare both turbines before and after the modification to verify the improvement.

In order to check the blade loads and the natural frequencies as well as the fatigue loads two field computers have been installed in the blades of the two “reference” turbines. The lead lag wise and the flatwise bending moments at the loads at the blade root were selected as the reference loads according to the technical specification IEC 61400-13 “mechanical load measurements” [5]. In order to limit the amount of data and keep the costs for the measurements low only triggered time series and long term statistics of the fatigue data were recorded as described in [6]. The measurement campaign before the modification showed similar data and behaviour of both neighbouring turbines which was expected. Also the technical availability was within the same order and in general typical for the type of turbine. Especially the load spectra from the blade root bending moment of both turbines were nearly identical over some months of monitoring. This information was very important as it was the basis for the investigation after the modification and the two turbines were operating in a wind farm of 11 turbines. Thus, for the typical long term operation the wind farm effects do not affect the loads of the two turbines selected differently. Also the natural frequencies of the blades have been assessed by fast Fourier transformation of typical time series of the two quantities at the blade roots of both of the turbines. The result before and after the modification as well as the predicted values from the calculations are shown in Figure 6 in details. The change of the flatwise bending frequency by -2.4 per cent is in the expected range and far away from any resonance points. In Figure 8 two cut-outs of a time series of the blade root bending moment lead lag wise are shown qualitatively. The time series are taken out of a measurement of the turbine number 6 (original) and the turbine number 7 (modified) at the same time from a wind direction without wind farm wake operation. The modified blade shows the typical signal of this load quantity without any surprising difference compared to the original. The wind speed at the measurement was close to rated wind speed.

Also the comparison of the fatigue loads - an example of which is given in Figure 9 - does not show any significant increase. In this Figure the flatwise and lead lag wise blade root bending moments are compared, where the turbine number 6 is the original and the number 7 is the modified one. The campaign was also a high wind speed period and both turbines were operating partly at rated wind speed and above.

5. Certification

From the beginning of the project the certification body was included in the process. For the modification described this was very important because the local authority had to be informed at an early stage. The certification body had to check the results of the calculations and to observe the tests and interpret the measurements. The project was far away of standard building permissions and thus, a close collaboration of wind farm operator, load calculating researchers and building was necessary. Finally, the prototype operation was permitted and started.

6. Results and Economics

A prototype set of a rotor blade tip extension has been designed, manufactured and successfully tested in laboratory and in the field. The measurement campaign showed the expected changes of the natural frequencies of about -2.5 per cent and it was proved that no resonances or undue vibrations exist. The modified turbine was tested up to high and very high wind speeds. No additional noise could be recognised, however, a standard noise measurement will be carried out in the future. The accompanying certification procedure proved to be an effective tool for the type of project.

The realised modification confirmed the expected production improvement by seven per cent. This could be validated by an operation of several months in comparison to the neighbouring turbine which was monitored in a long term campaign before. The return of investment of the serial modification will be about three to four years. Assuming an operation of another 12 years until achieving the turbines lifetime of 20 years it seems to be worth.

The assembly of the tips by using a lift without removing the blades with a crane and an expensive transport has been tested in laboratory. Therefore the overall costs of the modification of a single turbine promise an economic and ecological improvement without repowering a whole wind farm.

7. Outlook

Improving instead of repowering is a technical, ecological and economic solution. For similar turbines and similar sites the method described will be a solution for the improvement of the wind farms. Earlier mistakes in planning and energy prediction can be corrected. More turbines in similar wind parks will be investigated and equipped with an extension in the future. Furthermore the hysteresis of switching between the two modes of operation will be optimized. This can additionally reduce fatigue loads by minimising the number of switching events. As this can be done by changing the operation software only the costs are rather low.

As an additional effect the ecological quality of wind energy will be improved by enlarging the harvest factor.

8. References

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6. Figures

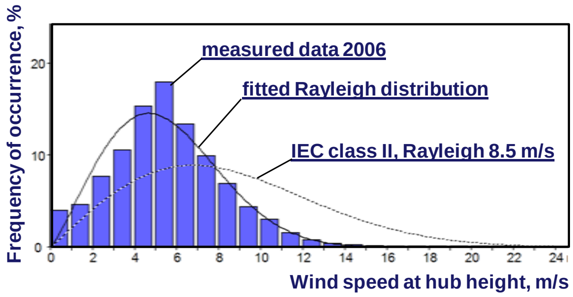

Figure 1 Measured wind conditions at the site of the wind farm. Turbine originally designed for IEC class II

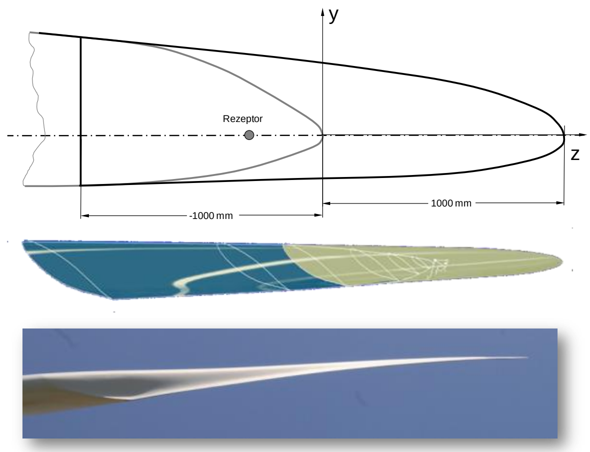

Figure 2 One meter extension, pre-manufactured, adjusted, glued and fixed in situ at the original blades. Lower picture shows the blade with extension during high wind operation.

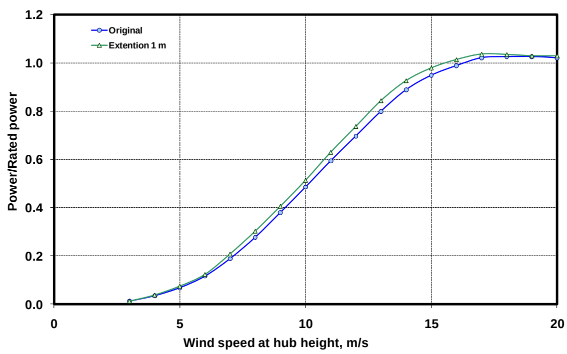

Figure 3 Comparison of calculated power curves with and without extension.

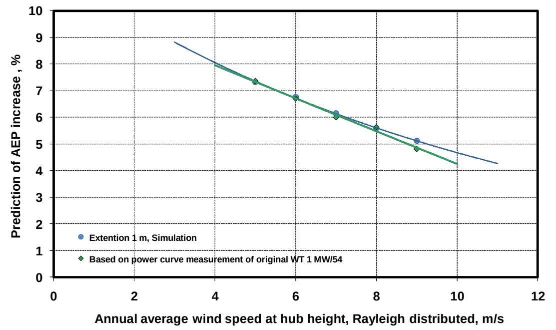

Figure 4 Calculation of annual energy production for the original and modified turbine for different annual average wind speeds.

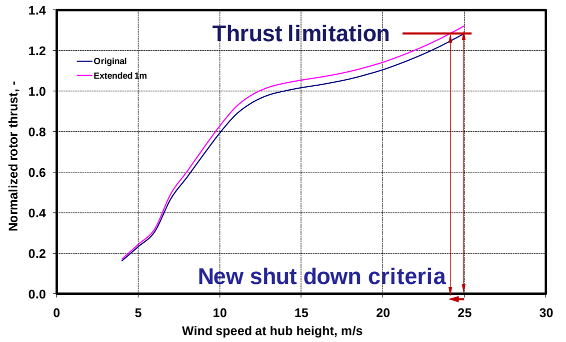

Figure 5 Calculated rotor thrust curves and new cut out criterion at constant thrust.

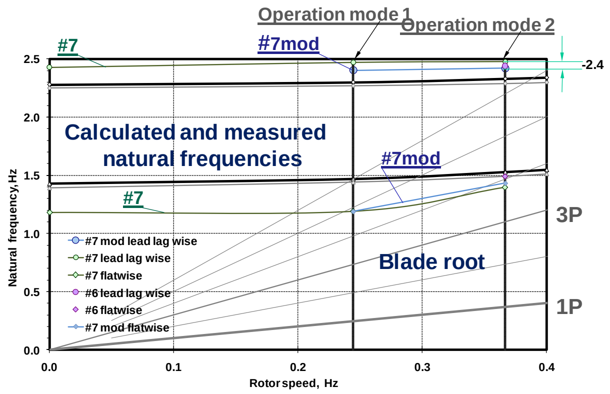

Figure 6 Calculated and measured Campbell diagram of the blade root. Comparison of the #6 and the modified turbine #7

Figure 7 Static load test of the prototype tip extension in the laboratory. The right side shows the deflection at maximum load.

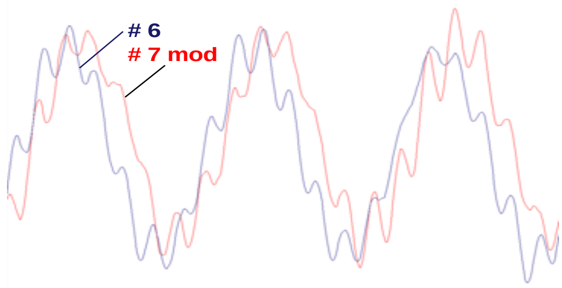

Figure 8 Time series of the lead lag blade root bending moment of the original (#6) and the modified (#7) turbine at high wind speed at the same time.

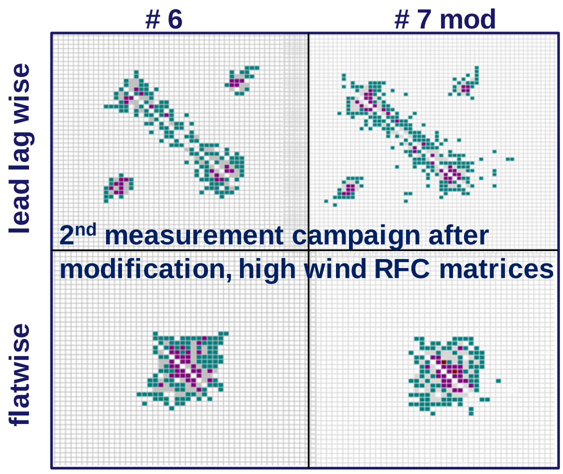

Figure 9 Long term Rainflow counted load spectra of the flatwise and lead lag wise blade root bending moment of the original (#6) and modified (#7) turbine from a measurement campaign including high wind speeds.