POWER PERFORMANCE VERIFICATION

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ABSTRACT: If wind turbine (WT) power curves are guaranteed in contracts they have to be verified by measurements. In order to reduce the costs sometimes the nacelle mounted anemometer is used for the power performance verification. The relation between the free wind speed and the nacelle wind speed has to be determined on another turbine of the same type with a meteorological mast at hub height in flat terrain. The limits of this procedure are discussed and possible solutions for shortcomings are suggested.
Keywords: Power performance, test methods, wind farm monitoring, guarantees

1 INTRODUCTION

The economy of a wind farm relies mainly on the available wind potential and the wind turbines' power performance. Performance assessment of a wind farm is often required in a contract between developers, financiers and manufacturers. Most wind turbine (WT) manufacturers guarantee the power performance of their products to their customers. There have been lots of discussions if the nacelle anemometer wind speed can be used for power curve verifications. The relation between the free wind speed and the nacelle wind speed has to be determined with a meteorological mast at hub height in flat terrain. The idea is to use this relation for the verification of the power curves of other turbines of the same type. The measurement costs are reduced significantly as no meteorological mast is needed for the nacelle power curve verification.

Measurement results from nacelle power curves are presented from machines in flat terrain, semi-complex terrain and extremely complex terrain. Some nacelle power curves were compared to mast measurements including a site calibration according to IEC. The flow inclination was measured with an ultrasonic anemometer. For some of the turbines the influence of changes in the operational characteristics (pitch angle, rotational speed) on the nacelle wind speed was investigated. The limits of the nacelle method (especially in extremely complex terrain) are discussed.

2 METHOD

A power curve relates the WT's electrical power output to the wind speed at hub height incident to the rotor in the ambient flow field. Because the nacelle anemometer is influenced by the flow distortion due to the nacelle body and the rotor blade roots, a correction to the unperturbed wind conditions is required. This wind speed correction is dependent on the nacelle's and blade root's geometry as well as on the mounting arrangement of the anemometer on the nacelle and must be specified for each type of turbine by means of mast measurements in the unperturbed air flow (see Fig. 1). A good opportunity to establish the nacelle anemometer correction are power curve measurements at prototype turbines in flat terrain according to the IEC standard [1] or the additional MEASNET guidelines [2]. Once the wind speed correction for the type of turbine to be tested is specified no met masts are needed for power curve verifications and the high cost for met masts can be avoided. This indeed makes this kind of power curve verification very attractive for wind farm operators and financiers to verify their WT' power curves.

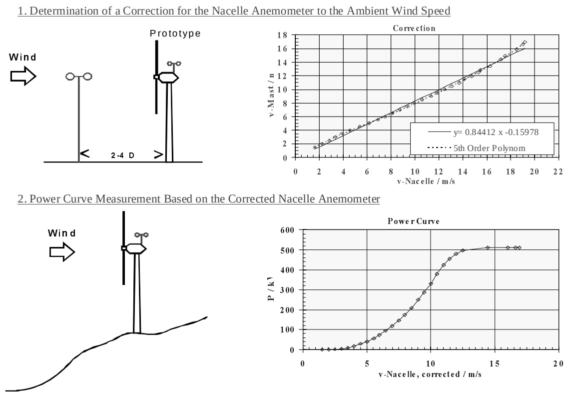

Fig.1 Methodology of power curve verification via nacelle anemometer

For a successful application of the nacelle anemometer in terms of power curve verifications, a number of requirements must be fulfilled:

- As anemometers of the same type can show significant differences in their wind speed dependence, a wind tunnel calibration of the nacelle anemometer should be performed. The nacelle anemometer must be calibrated by a qualified institution according to the MEASNET guidelines [3] (also from the turbine from which the correction was derived). It must be pointed out that wind tunnel calibrations are a critical uncertainty source for all kinds of power curve measurements. This is expressed by the fact, that nowadays within the MEASNET group [4] only the anemometer calibrations from three measurement institutions are accepted mutually and that only the calibration of these three institutions passed the Round-Robin test described in [5]. The MEASNET guidelines for anemometer calibrations will also be overtaken by a new IEA Recommendation "Wind Speed Measurement and Use of Cup Anemometry" which will be published within the next months.
- The mounting arrangement and the type of the nacelle anemometer must be identical at the turbine to be tested and at the turbine which served for the determination of the correction to the ambient wind

speed. To ensure the reproducibility of the correction the positioning and mounting arrangements of the nacelle anemometers have to be documented. Also the conditioning of the electrical anemometer signal has to be calibrated and documented.

- Cup anemometers can be sensitive to vertical inflow, i. e. wind vector outwith horizontal plane [6]. This is especially a problem for the nacelle anemometry, because the flow distortion by the nacelle and the rotor can induce additional vertical wind speed components. Thus, an anemometer insensitive to inclined air flow should be chosen as nacelle anemometer. Another critical aspect is the positioning of the anemometer on the nacelle (see chapter 4.3). Hence, the evaluation of a correction for a second nacelle anemometer position should be considered as an option.
- The correction must be based on the bin averaging of the mast wind speed upon the nacelle anemometer signal. The correction procedure (linear or higher order regression, binwise correction) must be chosen according to the associated uncertainty.

A principle shortcoming of this testing procedure is that the nacelle anemometer correction can be sensitive to the wind turbine settings (e. g. different pitch angles), against inclined air flow in complex terrain and also against operation of the WT in wake situations within wind farms. Intensive investigations of such limitations have been carried out in the EC co-funded project SMT4-CT96-2116 “European Wind Turbine Testing Procedure Developments”, results of which are reported below.

3 POWER PERFORMANCE VERIFICATION IN MODERATELY COMPLEX TERRAIN.

The power curve of a WTGS located in flat terrain is determined according to the IEC standard Furthermore, the relationship between the nacelle anemometer and the wind speed measured in the undisturbed air flow is established with a meteorological mast. This correction of the nacelle anemometer is applied for a power curve evaluation at a second turbine of the same type in moderately complex terrain, while all the requirements for a successful application of the nacelle anemometer listed in chapter 2 have been taken care for. The power curves of the turbines in flat and moderately complex terrain, both evaluated by means of the nacelle anemometer show no significant deviations (Fig. 2).

Only at wind speeds shortly below rated wind speed the flat terrain power curve is a little better than the power curve in moderately complex terrain, what coincides good with the higher turbulence intensity at the moderately complex terrain site [7]. The difference between the power curves in terms of the annual energy production is below 1 %, indicating that nacelle anemometry is an useful tool for power performance verifications.

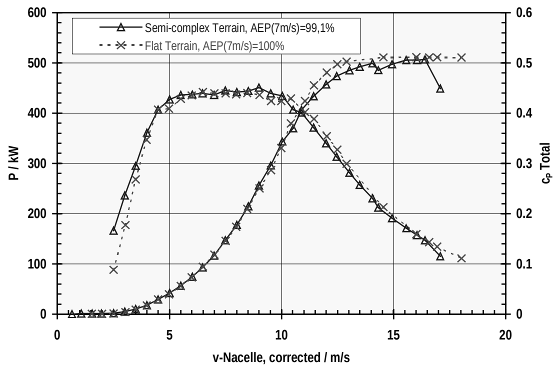

Fig.2 Nacelle anemometer based power curves of the same type of turbine in flat and moderately complex terrain. The same nacelle anemometer correction derived at the flat terrain site was used for both power curve evaluations.

4. LIMITATIONS

4.1 Influence of Turbine Settings

It is investigated, how far a nacelle anemometer correction remains valid if the WT’s operational settings are changed. This question is extremely important, as one major goal of performance verifications is to quantify the loss or gain of energy production due to such differences in the wind turbine settings (e. g. pitch setting).

At a wind turbine in flat terrain the influence of a change of the rotor speed up to 10 % on the power performance is investigated. The difference of the power curves due to the change of rotor speed control as evaluated with a met mast is well reflected by the power curve evaluations based on the nacelle anemometer, although the same correction for the nacelle anemometer was used for both rotor speed settings. The difference in AEP between both control schemes is 4.2 % according to the met mast evaluation and 4.7 % according to the nacelle anemometer based evaluation, implying that the nacelle anemometer at the specific type of turbine is insensitive against changes of the rotor speed.

At another turbine in flat terrain the influence of a change of the pitch setting on the power performance is investigated. According to met mast based measurements the power performance decreased by 4.5 % in respect to the annual energy production due to an imbalance of the pitch settings between the three rotor blades in the order of 1° compared to the case with equal pitch settings (Fig. 3). The tendency of the change of power performance due to the change of pitch settings is in tendency well reflected by the nacelle based power curves, when the same nacelle anemometer correction is applied for both pitch settings (Fig. 4). A decrease of power performance for the case with unequal pitch settings between rotor blades can be seen. However, the decrease of the power performance appears larger compared to the met mast based evaluation (6.8% instead of 4.5% in AEP). This is probably due to a small shift in the relation between the wind speed measured by the nacelle anemometer and the ambient wind speed caused by a change of the rotor induction.

To overcome this problem, when the relation between the free wind speed and the nacelle wind speed is determined on another turbine of the same type the turbine should be operated a short period for a different pitch setting in order to determine the influence of the pitch setting on the nacelle anemometer speed. Anyway, it is recommended to measure power curves of stall turbines at least for two different blade angles in order to get a measured power curve (e.g. for contractual matters) also for a blade setting which is used for the operation of the turbines high above sea level.

Another possibility is to change the nacelle anemometer position in order to find a position where the effect of the pitch setting is negligible.

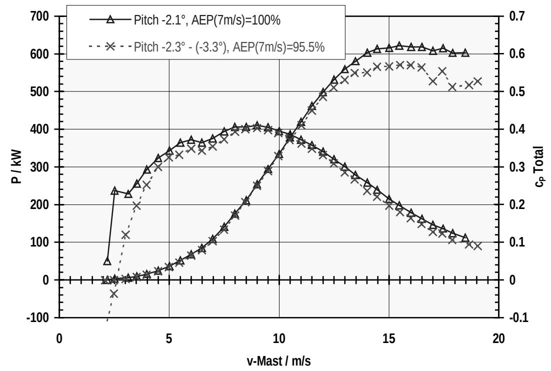

Fig.3 Power curves for different pitch settings based on met mast. A small imbalance between the pitch angles of different rotor blades of about 1° leads to a decrease of about 5 % in the annual energy production.

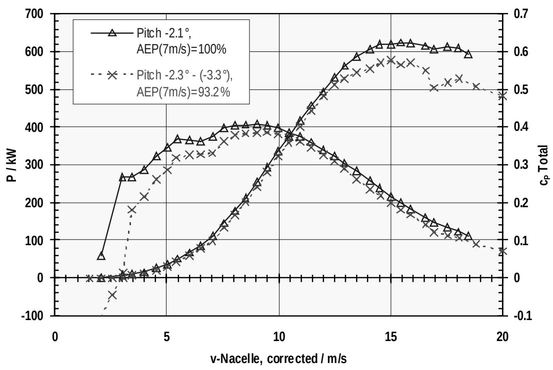

Fig.4 Same as Fig. 3 but evaluated with the nacelle anemometer. The same nacelle anemometer correction was used for both pitch settings.

4.2 Influence of Wakes within Wind Farms

Power curve measurements based on met masts according to the IEC standard can not be carried out at wind turbines located in the middle of wind farms. Due to the wake immersion of neighbouring wind turbines no position can be found for the met mast where the wind measured at the mast would be representative for the inflow of the WT. Power curve verifications based on the nacelle anemometer could be a solution for this problem, if the correction for the nacelle anemometer to the ambient wind conditions derived from another turbine located in unperturbed air flow remains valid in wake situations.

Fig. 5 shows nacelle anemometer based power curves of a wind turbine within a wind farm for a directional sector with the turbine in undisturbed air flow, direct wake situation and an evaluation without considering the wind direction. For all power curve evaluations the same nacelle anemometer correction derived for the free sector was applied. If the WT operates in the wake centre of neighbouring turbines the nacelle anemometer power curve is linked to severe errors. The reason is probably that the nacelle anemometer is located in the wake centre, where the wind speed reduction due to the wake effect is largest, while the rotor covers also the border of the wake and hence is immersed to a higher average wind speed. As a consequence the power curve derived from the nacelle anemometer is overestimated. If, however, the overall sector 0°-360° is used for the power curve evaluation, the wake effects are averaged out to some extend and the difference in AEP compared to the free stream power curve is only 2 %.

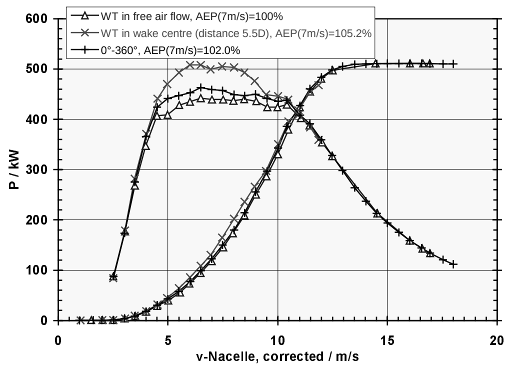

Fig.5 Nacelle anemometer power curves in undisturbed air flow, in the wake centre and without considering the wind direction. The same correction for the nacelle anemometer was used for all evaluations.

The problem of wake effects for power curve evaluations can be overcome by testing the directional sector for the data evaluation with the self consistency check shown in Fig. 6. The ratio of wind speeds measured with the corrected nacelle anemometer and evaluated from instantaneous measurements of the electrical power (on the bases of a temporary power curve) is bin averaged over the wind direction (see Ref. [8]). Wind directions for which the corrected nacelle anemometer is not representative for the wind speed incident to the rotor can be identified.

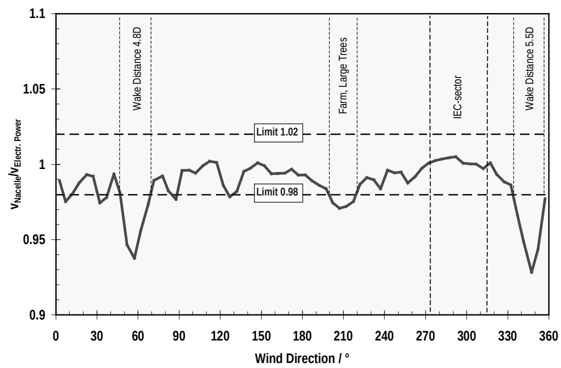

Fig.6 Self Consistency check for wind direction sector chosen for nacelle anemometer based power curve evaluations.

4.3 Influence of Flow Inclination

In very complex terrain power curve evaluations based on the nacelle anemometer can be linked to significant errors. If the terrain inclination is extreme, the flow distortion by the nacelle body (and rotor) can change caused by the vertical flow inclination. Hence, the nacelle anemometer correction derived for low terrain inclination might not be valid anymore. Fig. 7 shows power curves evaluated from a wind direction sector with steep terrain slopes.

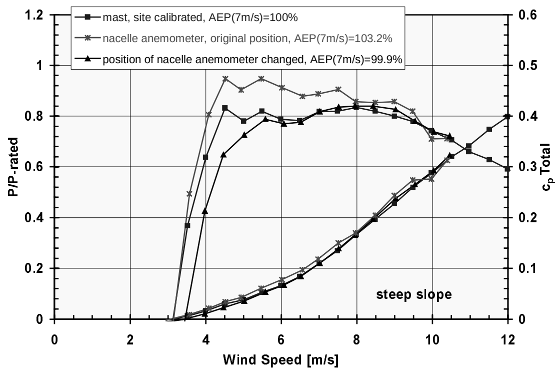

Fig.7 Power curves evaluated from a wind direction sector with steep terrain slopes. The nacelle anemometer correction derived for gentle terrain slopes leads to an overestimation of the power curve. The problem can be solved by lifting the nacelle anemometer (here from 0.7 m to about 2 m above the nacelle body).

The nacelle anemometer correction derived for gentle terrain slopes leads to an overestimated power curve compared to the mast based power curve (inclusive site calibration). The problem can be solved by choosing an appropriate positioning of the nacelle anemometer on the nacelle as illustrated in Fig. 8.

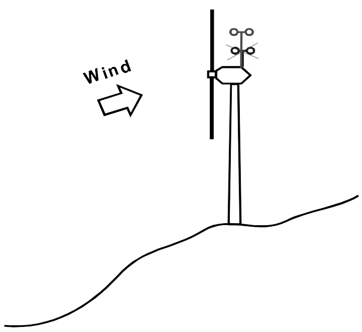

Fig.8 The sensitivity of the nacelle anemometer measurements to vertically inclined air flow due to steep terrain slopes can be reduced by changing the position of the anemometer.

After changing the position of the nacelle anemometer and determining a new nacelle anemometer correction from sectors with low terrain inclination the nacelle anemometer power curve within the sector with steep slopes fits well to the met mast based power curve (Fig. 7). Another solution is the application of the sector-wise consistence test similar to Fig. 6 in order to reduce the sector to certain limits in the slopes of the terrain.

5 CONCLUSIONS

In a lot of cases the power curve based on the nacelle anemometer is consistent with the met mast measured power curve in terms of the annual energy production. Typical uncertainties of power curve measurements according to the IEC standard are 5-8 % in flat terrain and 6-12 % in complex terrain (inclusive site calibration with two masts).

The differences found between the AEP from the nacelle and the AEP from mast measurements were in the range of only 1 % in moderately complex terrain, 2 % for small changes in the blade setting, less than 1 % for changes in the rotational speed and 2 % for wake situations when the Power curve is evaluated over all wind directions.

The limits are situations where large changes in the pitch setting lead to different results. A solution is the measurement of nacelle anemometer corrections (and power curves) for different pitch angles. Another limit occurs for steep slopes in complex terrain. Here the choice of an appropriate positioning and type of the nacelle anemometer can reduce the uncertainty of the power curve verification drastically. Alternatively, the reduction of the measurement sector according to the presented sector-wise self consistency check can be applied to solve problems in complex terrain. It must be recommended to also use this procedure for the reduction of the measurement sector if the WT to be tested is often directly exposed to wake situations

6 ACKNOWLEDGEMENTS

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