WIND SPEED MEASUREMENTS AND POWER PERFORMANCE VERIFICATION

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INTRODUCTION

The reliability of the economy of a wind farm is based on the accuracy of the assumed inputs for the energy yield prediction. Wind potential assessment and the power performance of the turbines are the most crucial points. The following risks are to be taken into account by evaluating a wind farm project (**due diligence**):

The site assessment starts with one (or several) **wind speed measurements** (preferably at hub height). The uncertainties related to wind speed measurements are varying between 3 and 20 (!) % in terms of energy production depending on the quality of the measurement system and the anemometer calibration (see IEA Recommendation 11: Wind Speed Measurement and Use of Cup Anemometry). Not only the mounting, the quality and calibration of the anemometers is important, but also the regular plausibility check of the data.

If the wind speed is not measured at hub height an **extrapolation of the wind speed** from the measurement height to the hub height has to be performed. The results obtained during the measurement period (usually one year) have to be correlated with the data from a nearby met **station (MCP= Measure Correlate Predict**) in order to get the **long term wind potential**.

Then a so called **micro siting** is performed in order to determine the wind potential at each turbines position within the wind farm area. The micro siting is usually done with a flow model and/or a mobile **SODAR** system. **SODAR** is a kind of acoustic radar with which we can measure the wind seed up to a height of 150 m with 5 m resolution. This system is very flexible and can be easily transported from one site within the wind farm to another site of planned turbine positions.

Next the **wind farm efficiency** has to be determined taking the wake effects of the turbines into account. Finally with the help of a measured power curve the **energy yield** of the wind farm has to be calculated taking the guaranteed **availability** and the guaranteed **power curve** of the turbines into account.

The **plausibility check** of a guaranteed **power curve** is a very complex task within the due diligence work. Questions have to be answered like: according to which standard and which quality assurance system the power curve is measured. Is the turbine planned in the project technically identical to the measured power curve (use of stall strips or vortex generators, contamination of blades, changes in the blade angle, noise reduction measures which influence the performance of the turbine) ? The verification method of the power performance has to be defined in the contract in all details in order to reduce the financial risks to an acceptable limit.

WIND SPEED MEASUREMENTS

Only best quality wind speed measurements will lead to accurate energy predictions. Not only the mounting, the quality and calibration of the anemometers is important, but also the regular plausibility check of the data. We are reading out the data each night via GSM and check all the data. A lot of experience is necessary to decide if data are plausible or if there could be something wrong with the measurement system. Questions to answered are for example:

- Which wind speed gradients (difference between wind speed at 10m and 30 m, depending on the wind direction)are within the normal range.
- What are the effects of snow or ice on the anemometers
- How can failures of the system (vandalism or lightning strokes) be handled.

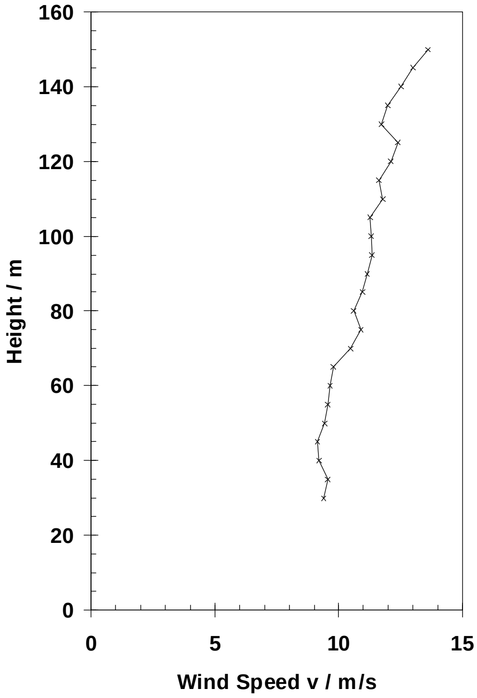
If such failures really happen we can nowadays (as we have a net of 50 wind speed measurements) do a correlation with one of the closest meteorological masts. This correlation (MCP) which is wind direction dependent requires proper time series of the wind data and possible changes of the wind direction between two met stations have to be taken into account.

If a wind speed measurement is only 1 % wrong you may loose about 30 % of your profit. A simple calculation is leading to this conclusion: Because of the 3. Power relation between wind speed and Energy production of a wind farm a 1 % change in wind speed leads to a 3 % change in energy production. If 90 % of the energy production is used for the re-financing of the wind farm project and 10 % of the energy production is your wind farm profit you are loosing 30 % of your profit if you loose 1 % of your wind speed (because you miss 3 % of the 10 % which are your profit). If you are more than 3 % wrong you may loose all your profit or go bankrupt.

From this simple calculation you can easily conclude: wind speed measurements are the most critical measurements for wind resource assessment, performance determination and prediction of the annual energy yield. In economic terms uncertainties translate directly into financial risk. There is no other branch where the importance of uncertainties in wind speed measurements is as great as in wind energy.

Error Sources	**Typical Uncertainties [%]**
Calibration of Anemometers	0.5 - 3
Selection of Anemometers (Flow Inclination Effect)	0.5 - 4
Mounting of Anemometers (e.g. boom effeects)	0.2 - 3
Selection of Measurement Site(s)	0.5 - 5
Measurement Period	0.3 - 3
Data Evaluation	0.1 -0.5
MCP (Measure Correlate Predict)	0.5 - 5
Total Uncertainty (Wind Speed)	**1.1% - 9.6%**
Uncertainty (Energy Production)	**3 % - 25%**

For the decision according to the optimum hub height and for micro siting in complex terrain we use a **SODAR** system (see figure below). **SODAR** is a kind of acoustic radar with which we can measure the wind seed up to a height of 150 m with 5 m resolution. This system is very flexible and can be easily transported from one site within the wind farm to another site of planned turbine positions.



The advantages of a SODAR system are:

- Remote Sensing of wind characteristics based on propagation of sound waves (SODAR = sound detection and ranging)
- Simultaneous wind speed measurements at different heights between 20 m and 150 m with a height resolution of 5 m
- Simultaneous measurements of all 3 wind speed components u, v, w
- High mobility of the SODAR-system provides a lot of advantages compared to met masts for measurements near wind turbines and for site assessment in complex terrain
- No flow distortion by mounting devices (advantage to meteorological masts)
- Wind speed averaging over a volume of some cubic meters better suited for wind energy than point measurements with anemometers

POWER PERFORMANCE VERIFICATION BY NACELLE ANEMOMETRY

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.

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.

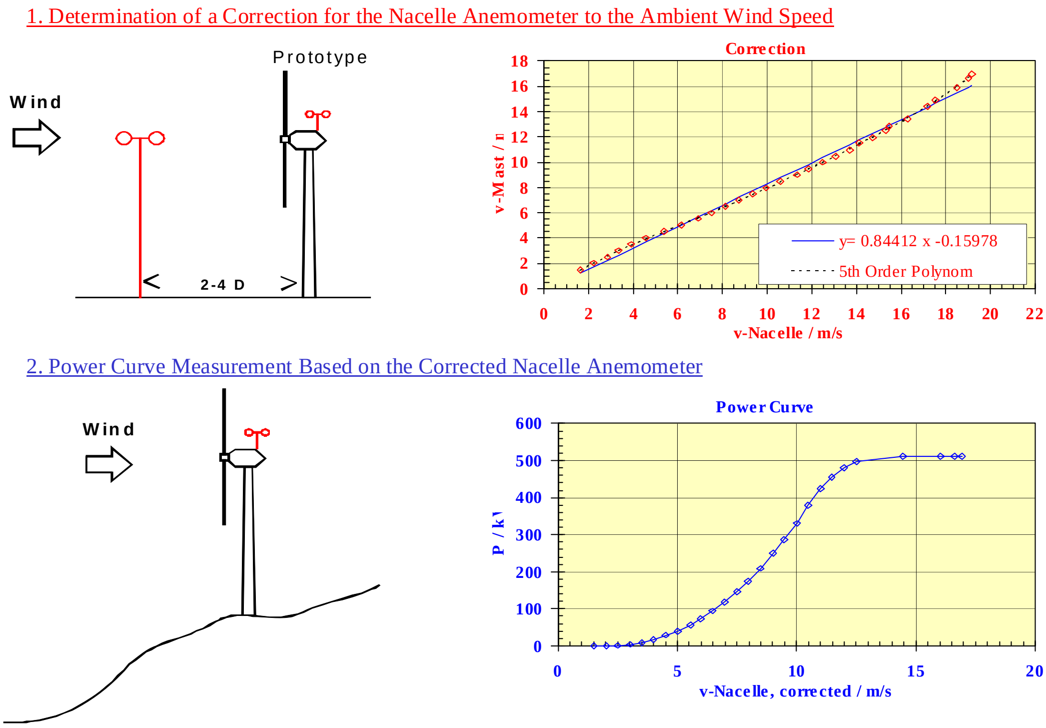


Fig.1 Methodology of power curve verification via nacelle anemometer

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”.

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