ASSESSMENT OF PERFORMANCES OF ULTRASONIC ANEMOMETERS AS ONE STEP AHEAD IN WIND MEASUREMENTS OF ENERGY PRODUCTION OF A WIND TURBINE.

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ABSTRACT

The most important uncertainties in the tests oriented to estimate the Annual Energy Production of a type of wind turbine, come from the wind measurements, in the determination of the power curve of the machine. The existing Standards indicate that wind measurements shall be taken by cup anemometers. These sensors are not able to measure some wind properties that affect power performance and that are proposed to be included in the future Standard´s revision, by recent research projects (mainly in complex terrain). Even, cup anemometers do not measure properly the reference wind speed, since they deviate before some wind conditions such as high turbulence, and wind vertical components. Ultrasonic anemometers present a serious alternative to be assessed.

1. INTRODUCTION

The accuracy of the AEP estimation mainly depends on the accuracy in the measurement of the power curve and therefore in the measurement of the wind speed. This accuracy can be split into two concepts, (already considered by the ISO 5725) that are Trueness and Precision. Trueness in wind speed means how close is the measured wind speed to the truth (in absolute terms) whereas precision indicates repeatability, that is to say, how small is the interval that contents several wind speed measurements (carried out in the same conditions) does not matter how close they are to the truth.

Trueness is affected since cup anemometers can not measure the complete wind speed vector, therefore the measure is systematically deviated from the truth.

Precision is affected since cup anemometers reading is influenced by parameters of the wind that are not normally known in real test, therefore, honestly, the total percentage of variation of the reading due to total range of variation of these conditions (Evaluated in previous tests) should be included as uncertainties.

Besides that, cup anemometers do not permit to measure parameters that have a proved influence in power performance.

2. PARAMETERS THAT AFFECT THE MEASURE

Cup anemometers reading is mainly influenced by two phenomena specially intense in complex terrain. These are turbulence in horizontal and vertical direction (Overspeeding) and vertical components of wind speed (Sensitivity to tilt angle).

2.1. Overspeeding.

Overspeeding is a quite well known phenomenon. It consists in a systematic overestimation of the wind speed due to the influence of the turbulence in the dynamic of the cups.

A good approximation given some years ago (see [5]) is the following:

$$\frac{\Delta U}{U} = I_s^2 J_s\left(\frac{L_0}{\Delta_s}\right) + cI_w^2 \qquad (1.)$$

Where:

ΔU: Over-estimation of the horizontal wind speed.
U: Horizontal wind speed.
I_s: Is the horizontal turbulence intensity.
I_w: Is the vertical turbulence intensity.
J_s: Is a function of the shape of the spectrum of horizontal turbulent energy.
L_0: Is the distance constant for the anemometer.
Δ_s: Is the characteristic length scale of the horizontal turbulence.
c: Is a constant of order unity.

In normal situation ($L_0/\Delta_s << 1$) the limit of the deviation of the over-estimation can be fixed to 10%.

The parameter regarding the anemometer that represents its quality before overspeeding is L_0 (distance constant, it resumes the first order dynamic response characteristics). The existing Standard fixed a maximun permited value of 5m. See [5] and [6].

2.2. Tilt effect.

In the majority of the situations (mainly in complex terrain) wind speed vector is not horizontal, therefore, it has a vertical component. All the known cup anemometers react before this factor in a unsystematic way. The effect of inclination of the flow, for the known high performance anemometers, ranges from -10% to 5% (depending on the sensor) for flow inclination of -15° up to -2.5% to 10% (depending on the sensor) for +10% of flow inclination. These results come from a test carried out at 8 m/s illustrated in [4].

3. PARAMETERS THAT AFFECT POWER PERFORMANCE AND CAN NOT BE MEASURED BY CUP ANEMOMETERS.

Latest research projects ([1] and [2]) have revealed that there are some parameters that affect the power performance of wind turbines in complex terrain (And even in flat one). These new parameters have some influence on mean power (therefore production estimation) and Std. of power (therefore associated uncertainty). Some of them, influence the wind sensor reading too, as it was commented in the point 2. These parameters are related to the characteristics of the turbulent flow (Deterministic and stochastic).

For instance, some differences in the way, the wind turbine reacts before turbulent flow, in flat and complex terrain have been detected, during specific analysis on real data for the same machine model, in both kind of terrain. [2]. This different behaviour reveals two degrees of sensitivity of the machine before the patterns or structures of the turbulent flow in complex and flat terrain.

Cup anemometers can not detect the dissimilarities between these two different turbulence patterns, since it is required to know the three components of the wind.

New parameters, that have not been considered in the analysis: Skewness and Kurtosis of wind speed, ratios of Standard deviations of different wind vector components at the same point or Karman fitting of the wind length scale. See [2]. The systematic inclusion of these factors in the Standard should be face since affect the power curve and can change from one place to other.

4 THE ROLE OF ULTRASONIC ANEMOMETERS IN POWER MEASUREMENTS.

Ultrasonic anemometers are also quite known in the wind related research issues. They can measure (3D types) the complete wind vector (u,v,w components) by taking advantage of the doppler effect in wind flow.

4.1. Results from real field test.

The fact of using the complete module of the wind vector given by a sonic sensor, its horizontal module or the value read by a cup anemometer, in the same mast at the same height, leads to completely different results and allows to find out the influence of turbulence intensity in horizontal and vertical direction in the relation between wind speed measured by cup anemometer and the horizontal wind speed measured by the ultrasonic sensor.

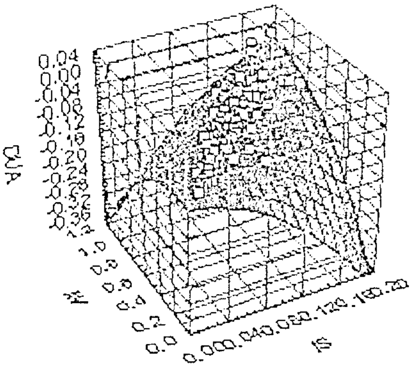


Fig 1. Difference between cup anemometer measure and ultrasonic horizontal wind speed as function of turbulence in horizontal and vertical component.

The influence of this, is finally described by AEP results, showing the differences for two wind speed references and for two ranges of turbulence.

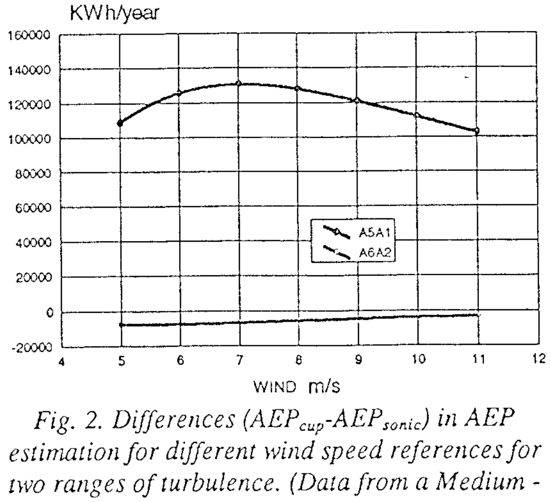


Fig. 2. Differences (AEP_{cup}-AEP_{sonic}) in AEP estimation for different wind speed references for two ranges of turbulence. (Data from a Medium - large size wind turbine)

Case	U_{cups}	U_{total}	T.I.
A5A1	•	•	<12%
A6A2	•	•	>12%

The case A5A1 presents the higher values. The reading of cup anemometers is lesser than the real wind vector. This leads to a displacement of the power curve to the left (to the higher probability wind speeds) and therefore to a higher AEP.

In the case A4A2 the phenomenon of overspeeding appears. The reading of the cup anemometer is higher than the reading of the sonic (It is closer than in A5A1 but this proximity is dependent of the outer conditions and it is not systematic), therefore the power curve regarding the cup anemometers displaces to the right (lesser probability region of wind speed) and therefore the AEPcup is lesser than AEPsonic.

4.2. The advantage of ultrasonic anemometers.

Ultrasonic anemometers do not have any mobile part, therefore they are not sensitive to dynamic effects, such as overspeeding.

Also, since they are able to measure the three components of the wind, they permit to calculate the parameters mentioned in point 3.

4.3. Specific questions regarding the usage of ultrasonic anemometers.

Ultrasonic anemometers are solution for these problems. Although they are quite expensive (One order of magnitude higher than cups models for the same quality) and also people need to be trained in its systematic use before any consideration in the future Standard.

This systematisation, mainly regards to the knowledge of the problems of these sensors, its way of usage and calibration.

4.3.1 Self induced disturbance and sensor calibration.

The measure given by ultrasonic anemometers is disturbed by its own structure. This influences the aerodynamic of the flow that arrives at the measure point. In general, the relation between the undisturbed (real) and disturbed (directly measured) wind speed vector could be established by means of a expression like the following one:

$$\begin{Bmatrix} u_{corrected} \\ v_{corrected} \\ w_{corrected} \end{Bmatrix} = \begin{bmatrix} C_{11}(\beta,\gamma) & C_{12}(\beta,\gamma) & C_{13}(\beta,\gamma) \\ C_{21}(\beta,\gamma) & C_{22}(\beta,\gamma) & C_{23}(\beta,\gamma) \\ C_{31}(\beta,\gamma) & C_{23}(\beta,\gamma) & C_{33}(\beta,\gamma) \end{bmatrix} \begin{Bmatrix} u \\ v \\ w \end{Bmatrix} \tag{2.}$$

Where:

$u_{corrected}$: Is the corrected component in the u axis of the sonic anemometer.
$v_{corrected}$: Is the corrected component in the v axis of the sonic anemometer.
$w_{corrected}$: Is the corrected component in the w axis of the sonic anemometer.
C_{ij} (i,j=1...3): Are calibration constants, determined in wind tunnel.

In general, it is not necessary to calculate nine calibration functions.

The most sophisticated (therefore most expensive) ultrasonic anemometers include a software that directly provides the corrected measure, by applying results from calibration test in wind tunnel. This is the case of the model RESEARCH by GILL instruments. For this sensor a simplified version of the expression (1.) is applied:

$$\begin{Bmatrix} u_{corrected} \\ v_{corrected} \\ w^{up/down}_{corrected} \end{Bmatrix} = \begin{bmatrix} M(u,v) & -D(u,v)M(u,v) & 0 \\ D(u,v)M(u,v) & M(u,v) & 0 \\ 0 & 0 & K(u,v)^{up/down} \end{bmatrix} \begin{Bmatrix} u \\ v \\ w \end{Bmatrix} \tag{3.}$$

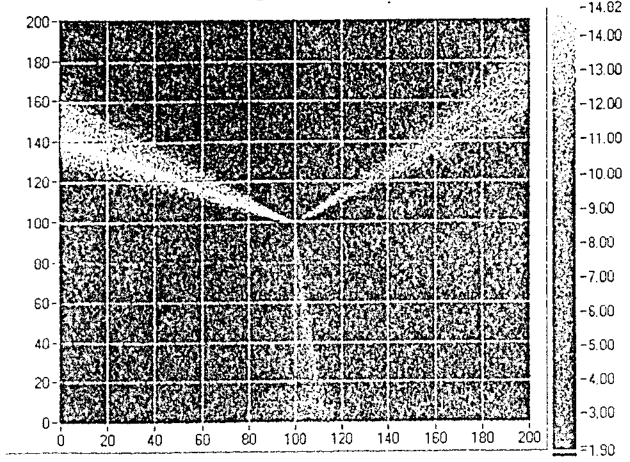
Where:

$u_{corrected}$: Is the corrected component in the u axis of the sonic anemometer.
$v_{corrected}$: Is the corrected component in the v axis of the sonic anemometer.
$w_{corrected}$: Is the corrected component in the w axis of the sonic anemometer.
$M(u,v), D(u,v), K(u,v)^{up/down}$: Are calibration functions, determined in wind tunnel.
u: Is the direct measurement of the channel u of the sonic anemometer.
v: Is the direct measurement of the channel u of the sonic anemometer.
w: Is the direct measurement of the channel u of the sonic anemometer.

The application of these methods of calibration, has a nice graphic representation. In the following figure the percentage of error in the reading of the wind speed module is presented as a function of the direction of the wind speed. The plane represented has as axis x the value of u component and v component as measured by the ultrasonic anemometer (ranging from -10 m/s to 10 m/s). The intensity of the colour represents the value of the error. The value of w component is fixed to 0 m/s in the first case and to -5 m/s in the second. All the results come from wind tunnel test.

In the graphs can be easily detected the pattern of the sensor thought the interference corresponding to each part.

Case without vertical component.



The disturbance range from 1.9% to 14.0 %.

Case with vertical component equal to -5.

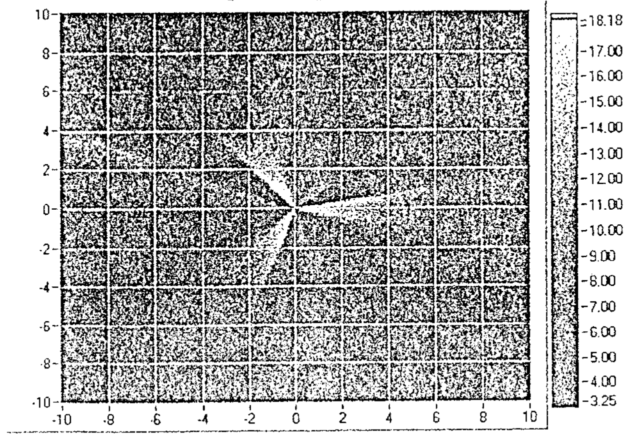


Figure 3 Self induced aerodynamic interference.

The disturbance range from 3.28% to 18.18%.A bit greater than in the previous case. This is due to de presence of vertical components since when this occurs, even the transmitters and receivers influence the measurement.

4.3.2. Wind tunnel calibration.

Matrices (2) and (3) or graph (3) requires quite expensive and time consuming test in wind tunnel (cost and time rather greater than in the case of cup anemometers). The procedure followed to carry out these calibration consists in provoking β and γ angles by the rotation and and inclination of the sensor inside the tunnel. After that recording the following measures is necessary.

U_∞	u	v	w	β	γ

Where:

U_∞ Is the wind tunnel speed.
u,v and w Are the wind speed measured components.
β and γ are the yaw and tilt angle of the sensor.

The set up of the test can be.

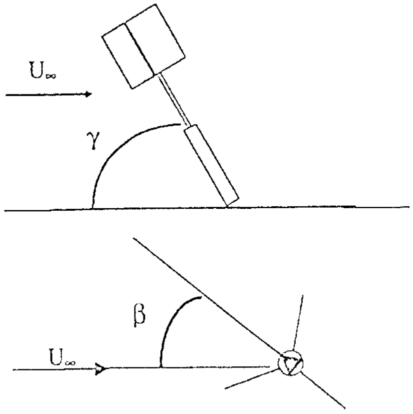


Figure 4 configuration of a test of a ultrasonic anemometer in wind tunnel.

Where:

β∈ [0,2π] and γ∈ [-π,π].

In this situation one can obtain the real 3D wind speed vector by means of the projection of U_∞ in the reference sonic. (u,v,w).

$$\begin{Bmatrix} u_r \\ v_r \\ w_r \end{Bmatrix} = [T_{TS}] \begin{Bmatrix} 0 \\ 0 \\ U_\infty \end{Bmatrix} \tag{4.}$$

Afterwards the relation between (ur,vr,wr) and (u,v,w) is obtained for each pair β,γ finding out relations such as (2.) or (3.).

5. CONCLUSION

Ultrasonic anemometer are likely to substitute cup anemometers in the test to obtain AEP of wind turbines since they read the complete wind speed reference. Although some problems regarding their usage should be solved, being calibration the most important (Besides the cost).

6. REFERENCES.

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