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Wind Sensor Characteristics under Icing Conditions on three 100m Wind Measurement Masts in North Sweden

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Abstracts

Wind measurements in northern and mountainous countries face specific conditions:

• Sensors are subject to icing conditions during extended winter periods.

• Short daylight periods and heated wind sensors require new power supply options.

• Complex terrain and high wind turbine hub heights require wind measurement with tall masts.

This study compares different - heated and unheated - types of wind speed and wind direction sensors on three 100m wind measurement masts (cup anemometers, wind vanes, propeller/vane combinations and 2D ultrasonic anemometers). Wind direction is compared among different sensor types. Wind speed measurements are compared regarding accuracy of wind speed, and turbulence under varying ambient conditions. The goal is to characterize sensors for reliable wind measurements in harsh environment including icing conditions.

Measurement Setup and Methods

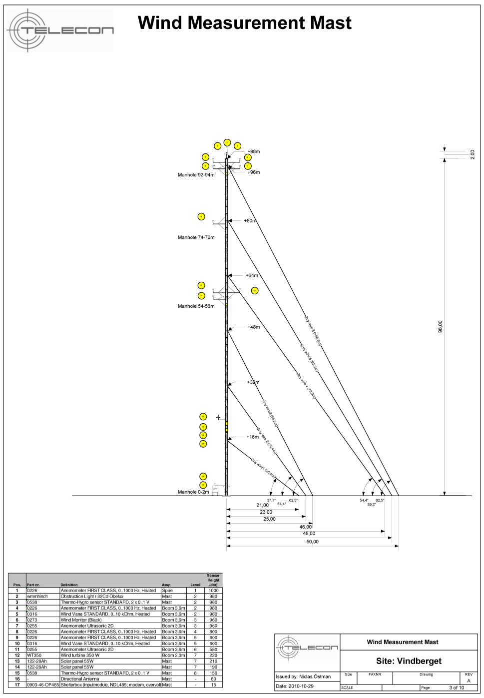

Fig. 1 Setup and configuration of 100 m masts

Fig. 1 shows the setup and configuration of the three masts which were used for this work. All sensors have been calibrated to MEASNET standard before installation. Data have been recorded by a data logger blueberry NDL485.

For this comparison only data from sensors close to the top of the masts and to each other have been used:

Height Sensor

100m: Top anemometer: Thies First Class wind speed (shaft heated)

98m: Reference anemometer: Thies First Class wind speed (shaft heated)

98m: Wind direction sensor Wilmers Standard (shaft heated)

98m: Thermo-Hygro sensor Wilmers Standard

96m: R.M.Young Wind Monitor Alpine, wind speed and direction (unheated)

96m: Thies 2D Ultrasonic, horizontal speed and direction (heated)

The following terminology is used for this document:

Cup = cup anemometer Thies First Class

Prop = combined propeller anemometer with vane R.M.Young Wind Monitor Alpine

Sonic = Thies 2D ultrasonic anemometer

In total, 10 months of data have been used for this evaluation.

Data analysis has been performed as follows:

• Filters: only sectors without mast influence => exclusion of boom direction +/-30˚

• Classification in temperature ranges: < -10˚ C = severe icing, < 0˚ C = icing likely, > 8˚ C = no icing

• Wind speed = 4..16m/s. All sensors have been calibrated according to MEASNET within this wind speed interval.

• The heated sonic anemometer has been used as reference for most correlations under icing conditions.

Fig. 2: Mast top with sensors

Fig. 3: Sonic anemometer, used as reference for most correlations

Results: Wind Speed

Correlation of different anemometer types under non-icing conditions

• Wind speed and turbulence intensity of all 3 anemometer types (cup / prop / sonic) correlate well. Cups and props correlate with the sonic with an R^2 of >0.998.

=> Even non-classified wind sensors, like sonics and props look suitable for wind measurements according to IEC

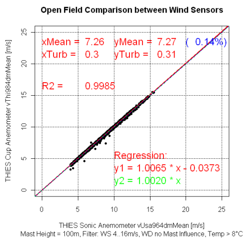

Fig. 4: Correlation of cup vs sonic no icing

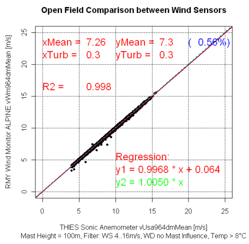

Fig. 5: Correlation of prop vs sonic no icing

Correlation of cup anemometers with shaft heating without icing and with icing

• At no icing, the top anemometer and the reference anemometer correlate well with R^2 = 0.9992 (Fig. 6).

• When icing occurs wind speed and turbulence intensity of the cups still correlate well with R^2 = 0.9942 (Fig. 7).

• Correlation between cup and sonic shows severe underestimation of wind speed by the cup (Fig. 12). Cause: the cups are covered by ice. This changes their aerodynamic characteristic. Due to shaft heating sensors continue to turn.

=> Sensors report faulty wind speed values

• Sensors on similar heights freeze simultanously. Icing cannot be detected from wind speed difference of these sensors or from distortion of vertical wind profile.

=> In situ comparison of top anemometer and reference anemometer as defined in annex K of the IEC 61400-12-1 does not recognize icing reliably [1].

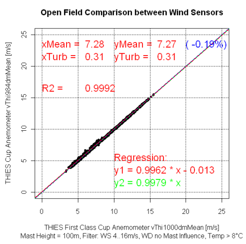

Fig. 6: Correlation of 2 cups without icing

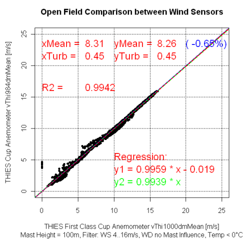

Fig. 7: Correlation of 2 cups with icing

Fig. 8: Light icing on cups

Fig. 9: Severe icing on cups

Icing effects on wind speed measured by cups and props

• Different domaines between approx. 30% and 70% of real wind speed could be identified caused by changes in drag coefficient due to iced cups (Fig. 10, Fig. 12). The shaft heating prevents the cups from being blocked. They never show 0m/s! Pictures in Fig. 8 and 9 show cups with different states of icing. These cups were still rotating.

• Props show less intermediate values (Fig. 11, Fig. 13). They are either blocked by icing or they show values close to the 1:1 line.

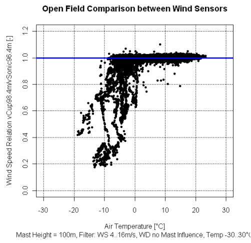

Fig. 10: Comparison of cup and sonic at different temperatures

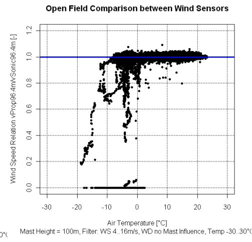

Fig. 11: Comparison of prop and sonic at different temperatures

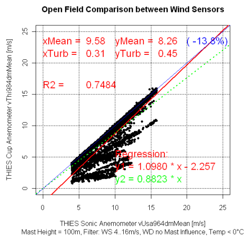

Fig. 12: Correlation of cup and sonic with icing

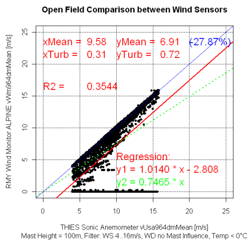

Fig. 13: Correlation of prop and sonic with icing

Results: Wind Direction

Comparison of wind vanes with shaft heating and Wind Monitors to heated sonics without icing and with icing

• Both sensor types correlate well with the direction values of a heated sonic anemometer (Fig. 14, Fig. 15).

• Due to the large gap between its fixed and rotating part the non-heated Wind Monitor proves to be as insensitive to icing as a wind vane with shaft heating and shows slightly lower scatter of data.

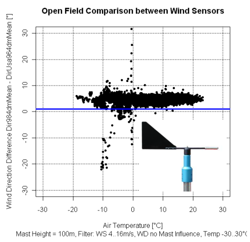

Fig. 14: Correlation of wind vane with and without icing

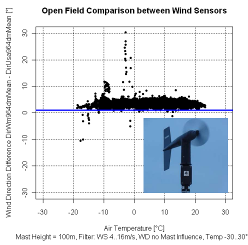

Fig. 15: Correlation of prop vane with and without icing

Conclusions

The data shown have been recorded at one mast. Both other masts show very similar results.

Open field comparison of IEC class one cup anemometers with shaft heating, combined propeller anemometers with integrated wind vane and wind vanes with shaft heating to heated sonic anemometers lead to the following results:

• All three types of wind speed sensors correlate very well under undisturbed conditions. Even non-classified sensors, like sonics and props are suitable for wind measurements according to IEC 61400-12-1.

• Iced cups of top anemometer and reference anemometer still correlate well with each other. Icing cannot be detected by simple comparison of these two sensors. Reliable detection of icing can only be achieved by use of a heated sonic anemometer as reference as it seems to work continously under icing conditions .

• Wind vanes with shaft heating and the Wind Monitor without heating provide reliable wind direction data even under icing conditions.

References

1. Power performance measurements of electricity producing wind turbines, *IEC 61400-12-1, First edition 2005-12 (E)*