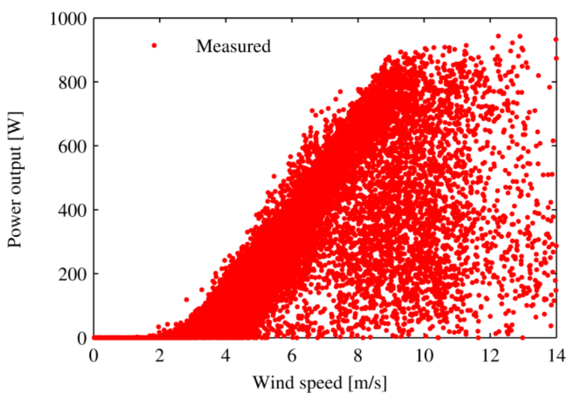
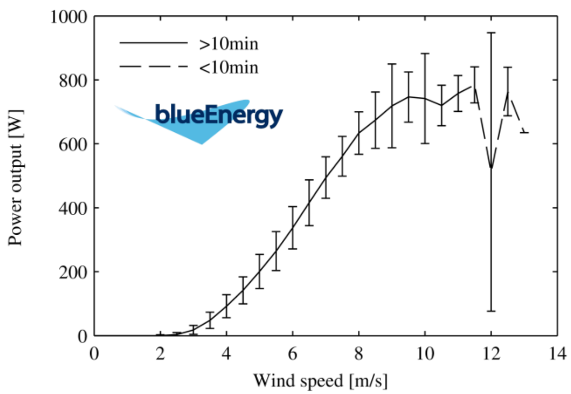
Measuring the Power Curve of a Small-scale Wind Turbine: A Practical Example





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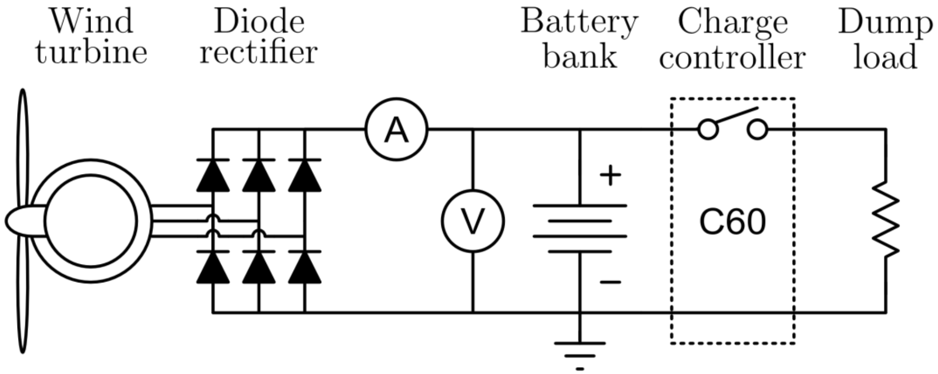
- We measure the power curve of a small-scale wind turbine system following IEC 61400-12-1 standard.
- We clarify the impact of various parameters: generator heating, battery voltage, controller settings, anemometer position.
- We give recommendations to ensure accuracy and reproducibility of the measurements.

I. Introduction

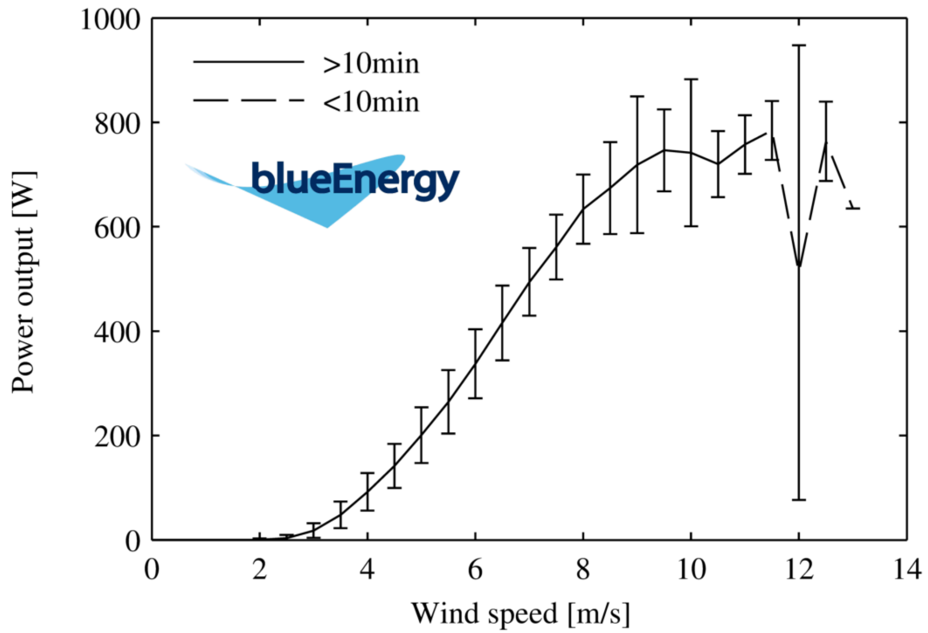
Small-scale wind turbine system

Test tower, wind turbine
and anemometer boom



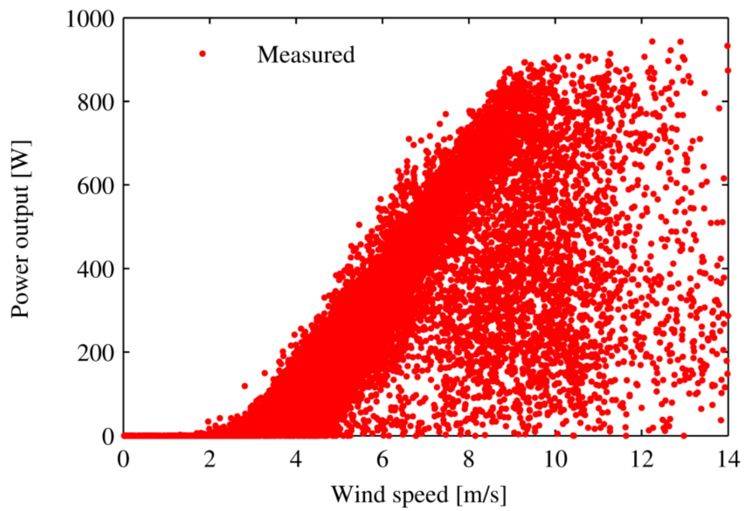
Power curve

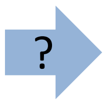
<u>Definition</u>: The power curve is a graph that represents the system electrical power output as a function of the wind speed.

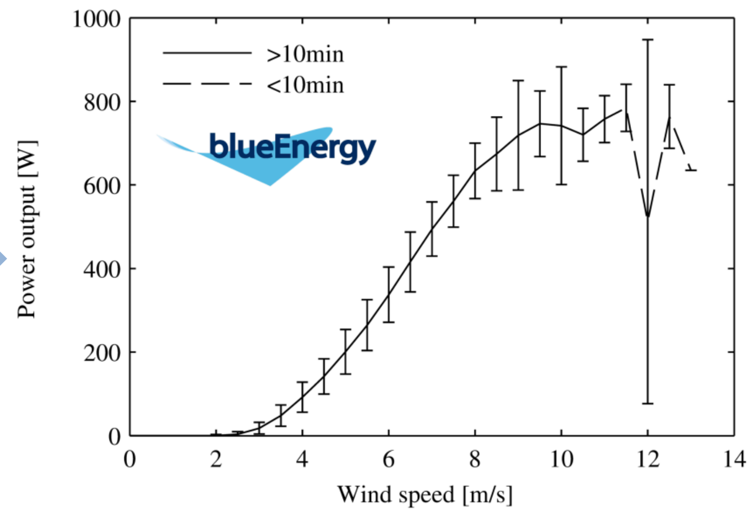


II. Measurement

Results







What we measure

What we want

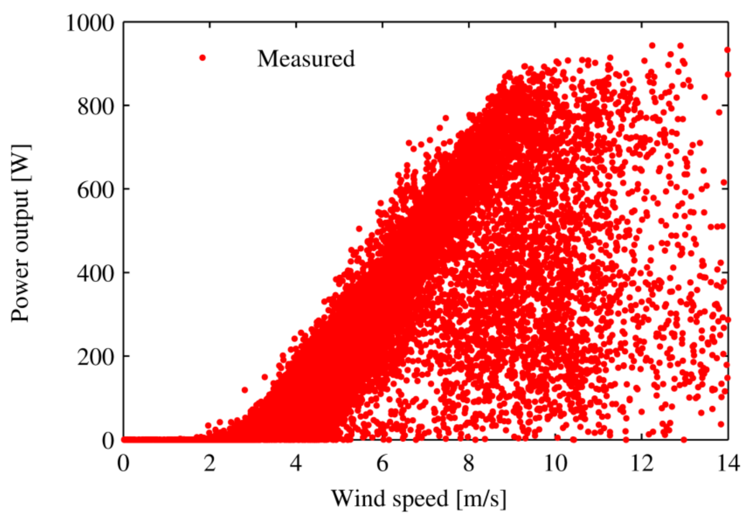
Why is there so much scattering ?

How do we get the power curve of the system from the measured data set ?

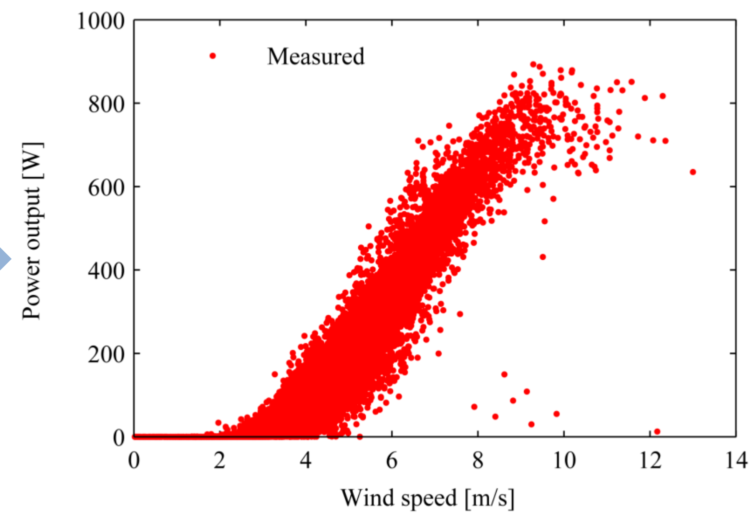
Is the procedure consistent ?

III. Influence of parameters

Influence of battery voltage



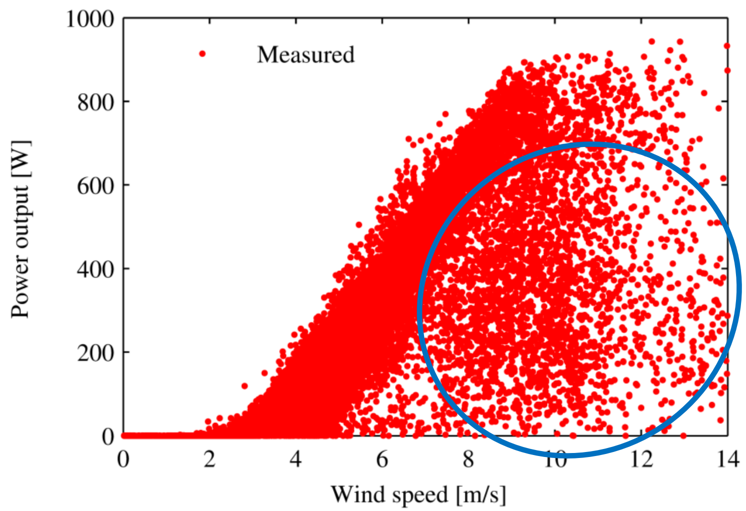
21.66V < Vdc < 30.24V

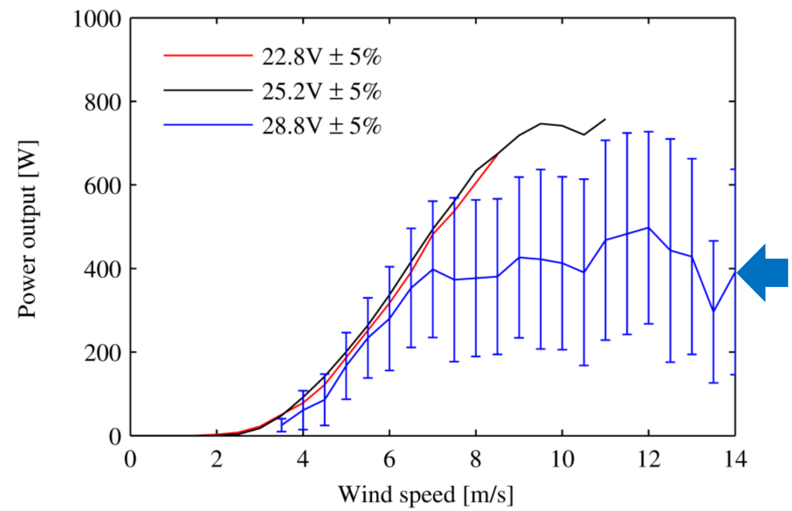


23.94V < Vdc < 26.46V

At a given wind speed, the power output of a battery-connected wind turbine depends on the voltage of the batteries. The power curve should be independent of the particular battery configuration. To this end, IEC standard requires to set the battery bank voltage to 25.2 V. The scattering caused by a fluctuation of the battery voltage is 40 W for a wind speed of 7 m/s. Following the standard, we select only the data with a battery voltage of 25.2V$\pm$5%.

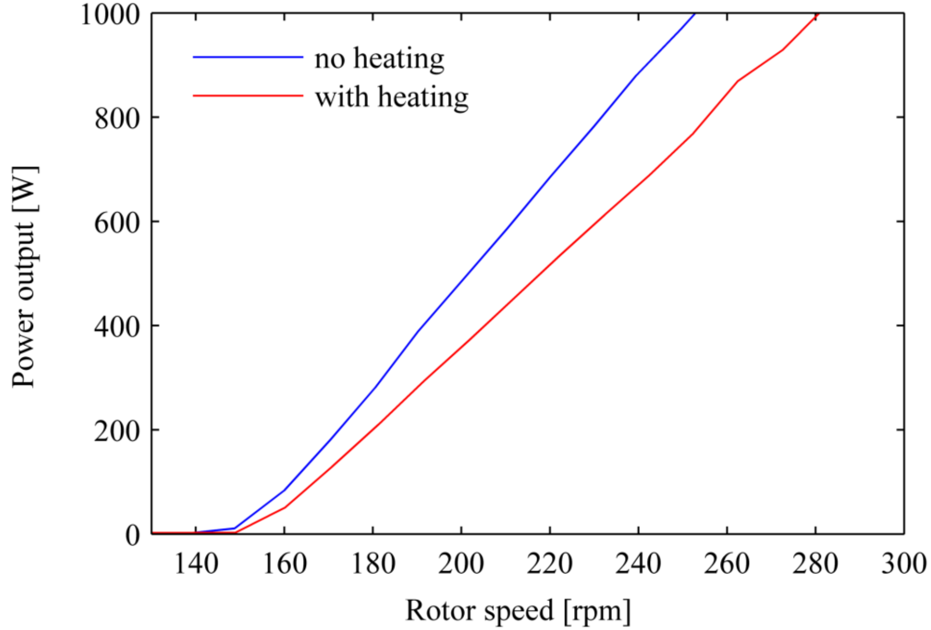
Influence of controller settings





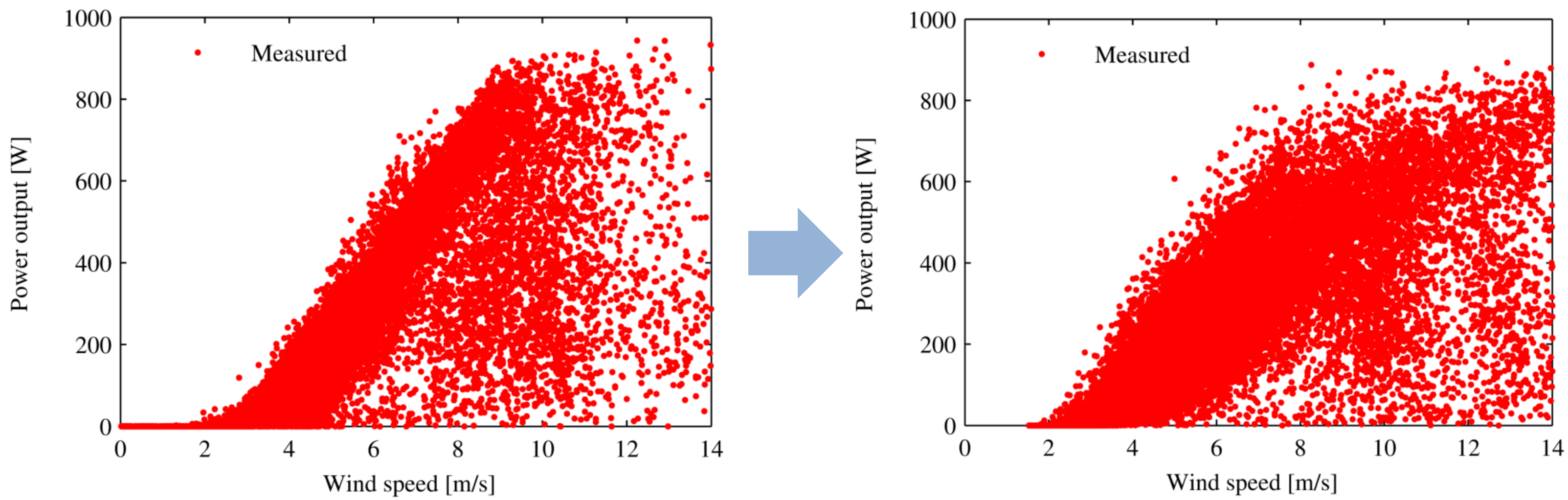
Following IEC standard, the systems includes the charge controller and the dump load. The charge controller is connected in parallel to the generator rectified output. It diverts the energy to the dump load when the battery voltage rises above a preset level (26.4 V here). This happens when the battery is fully charged or during wind gusts. The resulting effect can clearly be seen on the 28.8V ± 5% power curve: the output power has a large standard deviation and drops in average.

Influence of generator heating



Small-scale axial flux generators can have important localized heating because of (1) their high power density, and (2) their poor thermal design in comparison with large-scale machines. To illustrate the potential impact of generator heating on electrical output power, we carried out test bench measurements. The scattering caused by generator heating can reach 50 W at 175 RPM. This gives us an upper bound on power loss due to machine heating.

Influence of anemometer position



Anemometer situated on a boom on the test tower

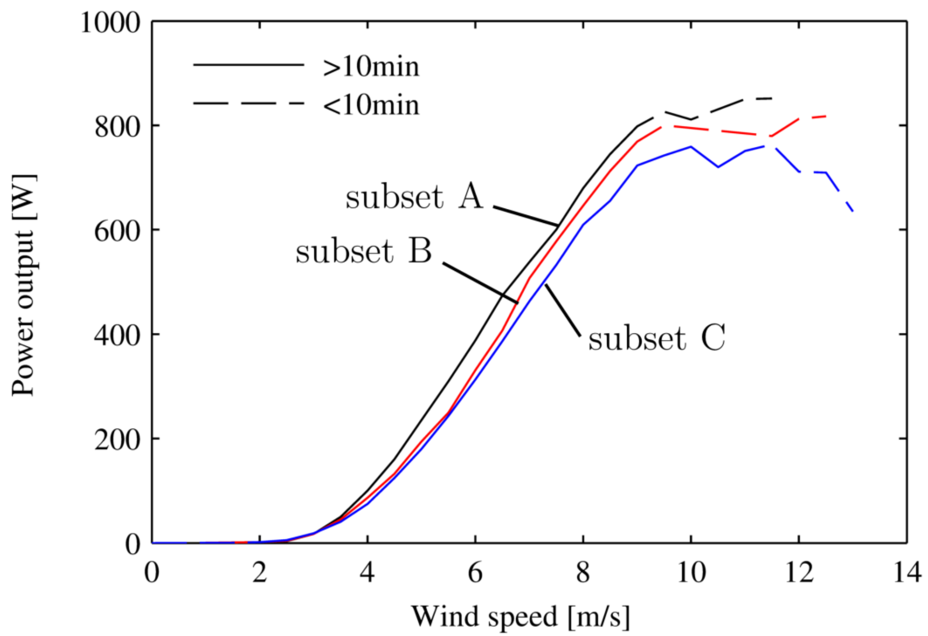
Anemometer situated 40m away from the test tower

To illustrate the influence of the anemometer position, we recorded simultaneously the wind speed on a meteorological mast situated 40 m away from the test tower. Note that the maximum distance allowed by the IEC standard is 4 times the turbine diameter, ie. 14.4 m. The wind speed error between the two towers can stretch to 2 m/s.

III. Consistency

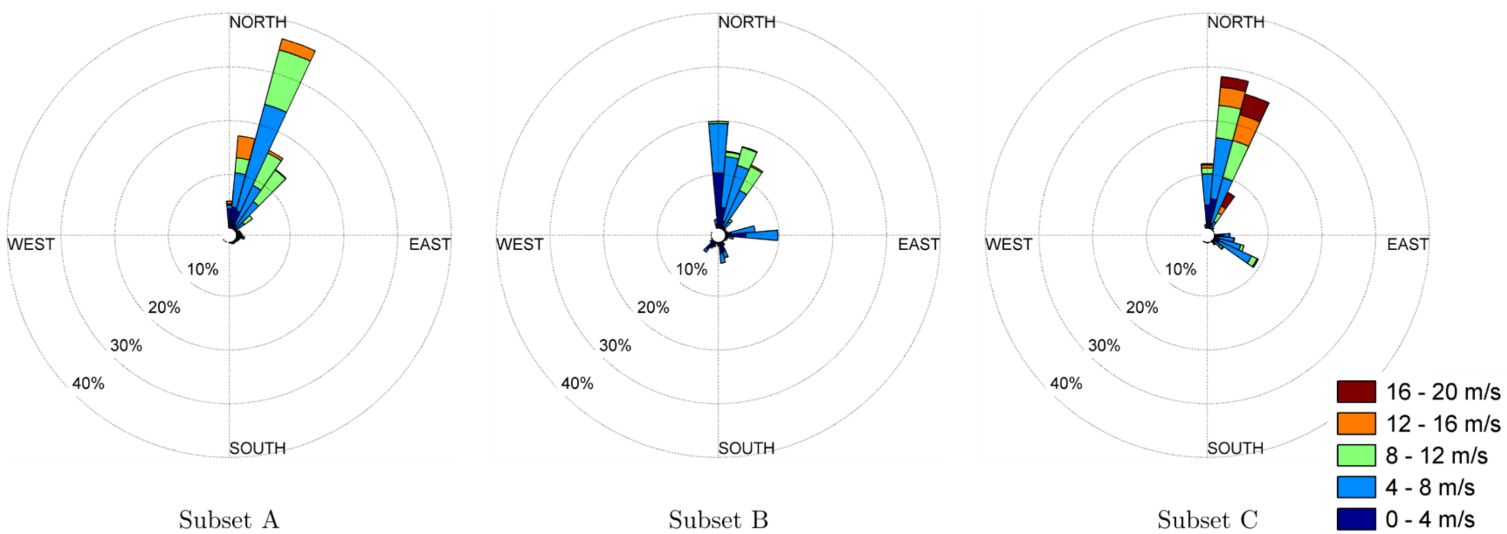
Consistency (1)

The procedure should be consistent and reproducible. To test it, we extract 3 subsets from the main dataset. Each subset meets requirement of the standard. Then we plot the power curves for each subset. We observe a lack of consistency and reproducibility: at 8 m/s, the average power output varies between 610 W and 680 W.



Consistency (2)

The power output variation is clearly not due to the wind direction because it is almost constant. But it can be a consequence of the different wind speed distributions: subset A has mainly low and moderate winds, subset B has mainly low winds, subset C has mainly moderate and strong winds. At high speed, the SWT generator typically tends to heat up, the battery voltage tends to rise and the charge controller tends to connect the dump load. A combination of these effects could explain the lack of consistency.



V. Conclusion

- Following the IEC 61400-12-1 standard, we measured the power curve of a stand-alone small-scale wind turbine with battery energy storage.
- We observed a lack of consistency when analyzing various data sets.
- We investigated the parameters that could be responsible for such a variation: generator heating, battery voltage, charge controller settings, generator inertia and anemometer position.
- We recommend including error bars with power curves, increasing the size of the usable database, rejecting system manual start data, and installing the anemometer on a boom on the same tower as the wind turbine.

Matlab code available

http://www.mathworks.fr/matlabcentral/fileexchange/45888-power-curve-of-a-small-scale-wind-turbine-system