Evaluation of Correlation the Wind Speed Measurements and Wind Turbine Characteristics

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Abstract: The renewable wind power generation spreads over. The application of wind turbines requires wind prediction and nation wide production control. The generation forecasts are based on measurements, models and wind turbine characteristics. In this paper we introduce the validation of the characteristics through the definition of the relationship between the real measurements. We found that the pure remote wind speed and production measurements are not correlated. Reordering these data, applying the cumulative distribution function, we can come close to the 'factory characteristics'. Defining the ratio between the measured characteristics and factory characteristics, we can find the practical relation between a remote wind speed measurement and a local wind at the turbine. This approach is based on energy production of a longer time period.

Keywords: wind turbine characteristics, wind speed and generator output correlation

1 Introduction

1.1 The Situation of Wind Generation in Hungary

Hungary is located in the middle of Europe, the wind climate is modest. The country is poor in primary and renewable energy sources. In spite of these facts, at the end of the year 2006 more than 60 MW wind turbine capacity was installed by 40 wind turbines (see Fig. 1). The close target is the installation of 330 MW, but there exist other plans for 1300 MW more. There are a lot of arguments for and against wind energy. As an advantage the clean production can be mentioned, the opposition argues with high prices and the poor control capability of the power system.

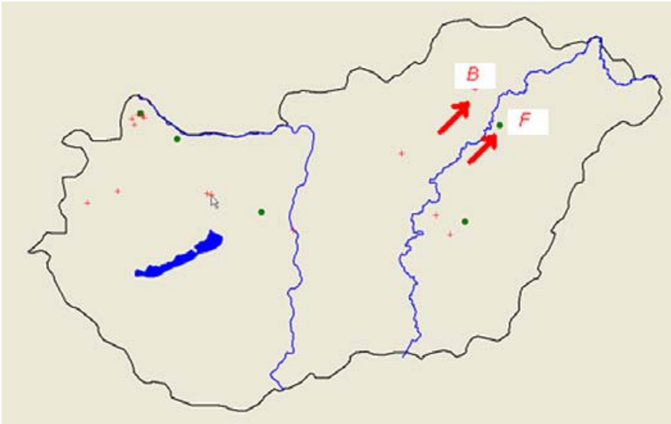

Figure 1
Wind parks in Hungary, 2006

1.2 The Need for Evaluation of the Real Measurements

The wind turbines are developed by only a small number of vendors in the world. The practical application means the planning, setting up, operation and control of wind energy. There are more aspects why to investigate the real measurements of the existing towers:

- *Production schedule forecast:* The system operator must know in detail all the generation schedule for security and reserve reasons [1].
- *Determining the upscaling factor:* The wind speed is rarely measured in 100 m heights. The upscaling factor defines a ratio between the measurements in the lower heights and in the heights of the turbines. In case of application of the Hellman formula, we speak about 'exponent' [8]. The forecast models use a general and theoretical upscaling model for the wind generators. All the wind measurement – generator output pairs should be checked.
- *Defining the forecast/measurement point:* Meteorological measurement points are bounded, the wind measurements from the tower do not stay at the disposal for the system operator.
- *Validation:* All the investment and operational plan must be validated by real measurements.

2 Characteristics Measurement

2.1 The Factory Characteristics

In the project we investigate a V-27 turbine at 'Bükkaranyos' (see 'B' on Fig. 1) and wind measurement ant 'Folyás' meteorological station (see 'F' on Fig. 1).

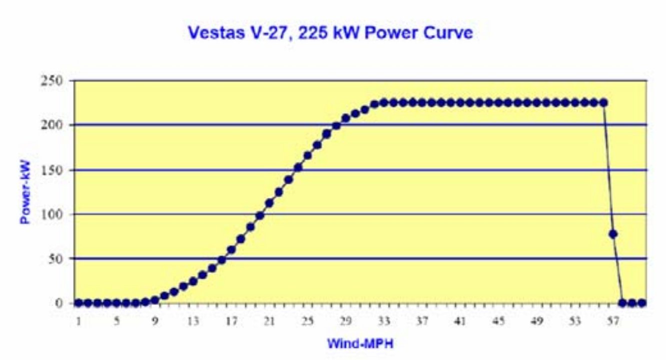

Figure 2
Factory characteristics of the investigated V-27 turbine

Fig. 2 shows typical characteristics of wind turbines. This curve is measured in stationary mode, it does not contain the effect of local turbulences, direction changes and wind speed differences between the upper and lower part of the (spinning) rotor measurements.

According to Watson the right wind forecast in 2-4 hours is crucial for the cooperative operation of the wind parks in the power system. The forecast must be based on historical-statistical data, correlation analysis and any model if there is. Watson [3] investigates the correlation between tower measurements and on sea / on shore measurements. The correlation analysis of the forecasted and measured data is the test of the wind prediction model [4]. Bechrakis [5] uses neural networks to simulate the correlation between two independent wind measuring stations (uses the sample cross correlation function – SCCF).

2.2 Characteristics Based on Pure Measurements

Measuring the wind speed and the generator output, we should get similar characteristics to the ones stated by the factory. We use the power output values calculated from 15 minutes energy production. The wind speed measurements come from the National Meteorological Database, showing the actual wind speed in every 10 minutes.

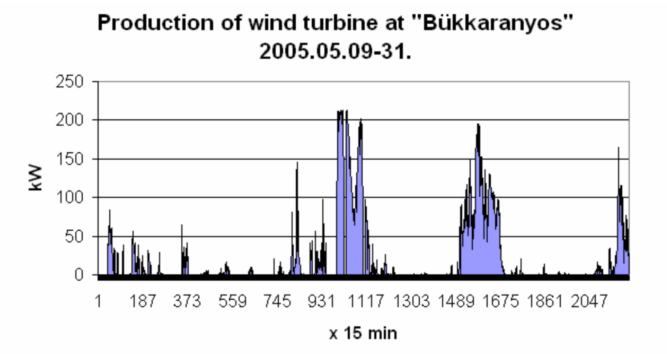

Figure 3
Generator output in real-time

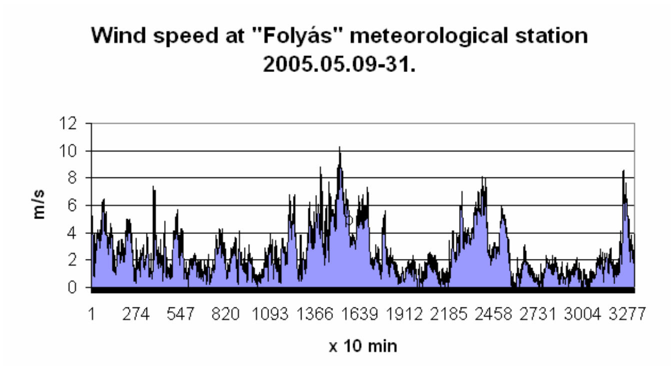

Figure 4
Real-time wind speed measurements

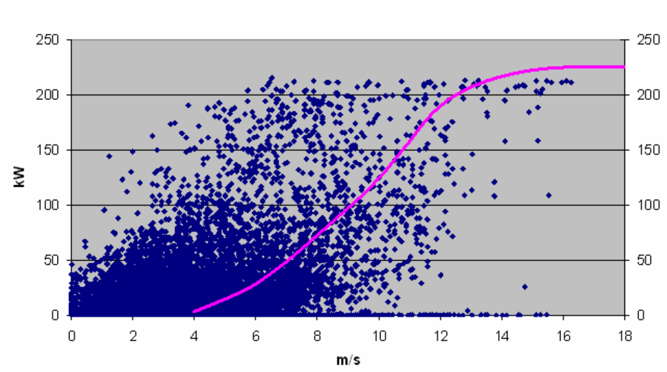

Figure 5
Wind turbine characteristics based on real-time

Figs. 3 and 4 show our generator output measurements and a wind speed measurements in some kilometers distance from the generator. The real-time and synchronized measurements of the wind speed and generation output ***do not*** show any correlation (see Fig. 5). Christiansen presents similar wind speed – production curves for wind farms [7]. Heimo mentions the necessity of the synchronization of the measurements [6].

The causes of the bad correlation are

- The *distance* between the wind turbine and wind measurement.
- The local wind turbulences that create difference in the wind blow at the two measurement points. Figs. 6-7 show the fast (1-6 sec), the medium (1-6 min) and the slow (1-6 hour) changes. The fast and medium wind speed and direction changes are not handled (followed) by the turbine, it causes *deviances*.
- Turbine dynamics and measurement *errors*, etc.

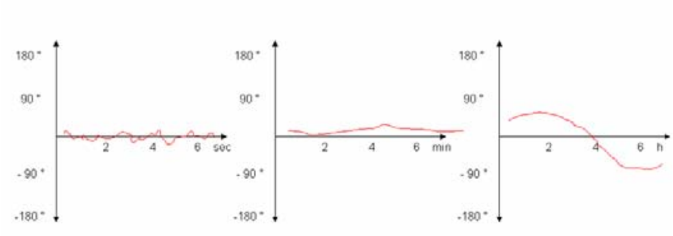

Figure 6
Wind speed changes

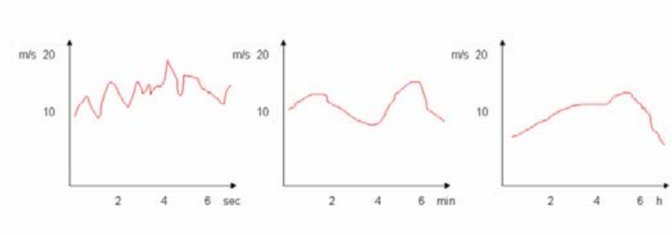

Figure 7
Wind direction changes

As the above measurement shows on Fig. 8, the wind blow is rarely stationery (the measurement was performed near Budapest). The horizontal line is the average wind speed in the investigated hour (2,3 m/s) meanwhile the speed changes between 1 and 5 m/s.

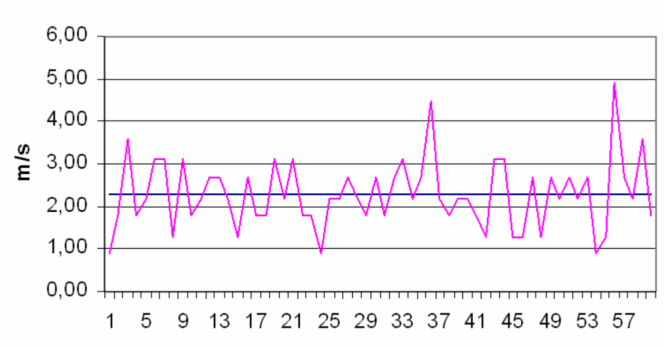

Figure 8
Wind speed changes measurement on minute scale

2.3 Distributional Reorganization

An ideal wind speed and power output measurement at the same tower should give the factory characteristics of the wind turbine, the two measurements correlate on the factory curve. It is valid for all the moments of the investigated period. (We do not handle the mechanical dynamic of the turbine.) If we prepare the cumulative distribution function of both measurements, the previous correlation is still valid and we get the same curve. (The two non monotonic functions are sliced into small pieces and sorted into monotonic functions.)

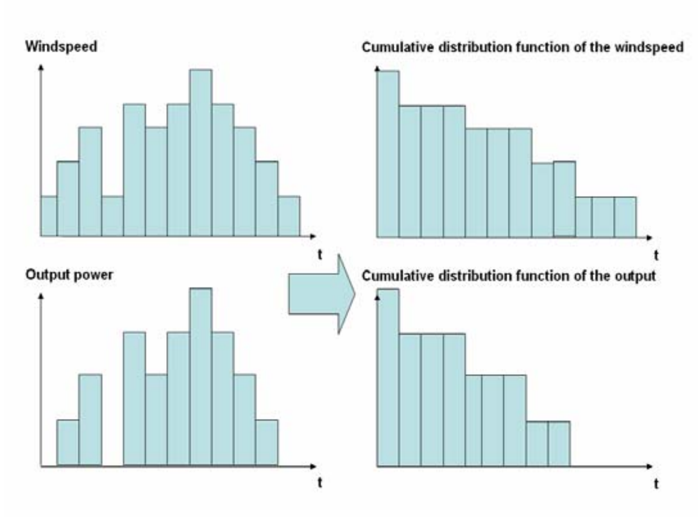

Figure 9
The functional transformation

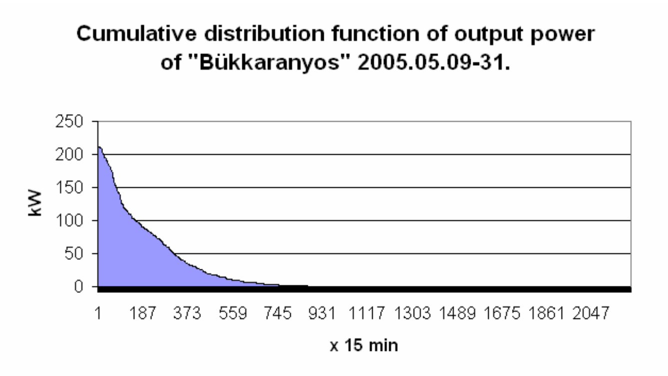

Figure 10
The transformed power output function

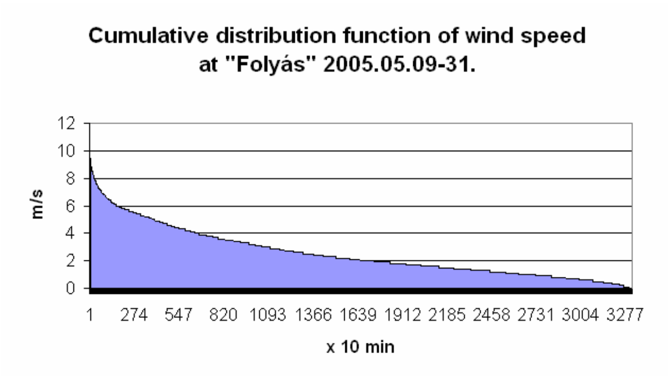

Figure 11
The transformed wind speed function

2.4 Characteristics Matching

Based on the above mentioned, the locally differently running curve is substituted by a globally similarly cumulated distribution function. We investigate not the specific synchronized moments but the same period, so we integrate the power into generated energy. This is an energy-based characteristics retrieval. Figure 12 shows characteristics similar to the factory characteristics (marked by dots).

The figures were results of measurements during a 23 day long period. We used the same data, but reordered them, as seen on Fig. 5. The wind speed measurement is placed 10 m above the ground at 'Folyás' station and the turbine rotor is in 33 m height in 33 km distance.

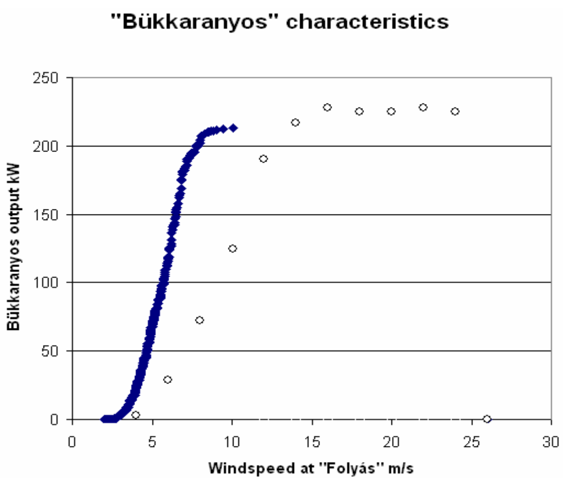

Figure 12
Measured function of the wind speed and the generator output (the dotted line is the factory characteristic of V-27 turbine)

3 Relationship of Distant Measurements

The meteorological forecasts are based on global models that use e.g. 9 km x 9 km horizontal base squares with 100 m high vertical steps [2]. The problem is that the primary estimation points and the meteorological stations no coincide with the turbine position (see Fig. 13). The meteorologists can interpolate the forecasts values for the mediate points, but it is only a derivative value of the primary measurements.

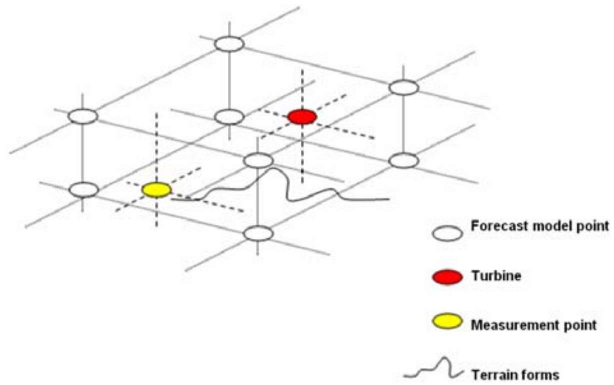

Figure 13
The relation of the measurement point, forecast point and turbine position

Getting the factory shape characteristics we can state, that the energy based wind turbine characteristics measurement can use the wind speed measurements of a neighborhood point, where the wind is 'similar', where the wind has the same energy content. What does it mean neighborhood? As Table 1 and Fig. 14 show the curves based on measurements in 200 km distance are a little bit distorted, but in the 30 km 'Folyás' station produced really similar curve. It can already mean 'the same place'. This produces the closest curve to the factory characteristics. The closest 'Folyás' wind measurement's curve produces the best fit (see Fig. 14). It tells us that in case of flat terrain we can use the meteorological data in some km distances we do not have to recalculate it for the exact turbine position.

Name of wind measurement place	*Distance of the wind turbine 'Bükkaranyos'*
Folyás	33 km
Agárd	187 km
Túrkeve	98 km
Mosonmagyaróvár	263 km
Győr	238 km

Table 1
Distance of the tower and the wind measurement points

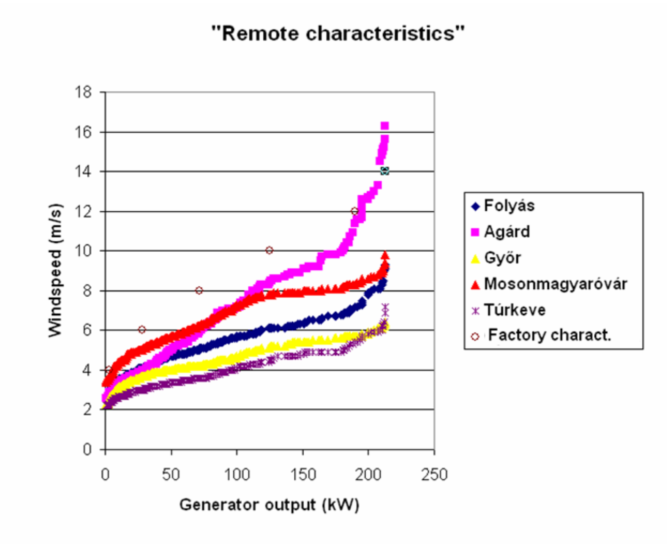

Figure 14
Different fits of different measurements
(the dotted line is the factory characteristic of V-27 turbine – the axes are transposed)

3.1 Rating/Upscaling

If we use a remote wind speed measurement, we have to define the coefficient that creates a simple relation between the two measurements. For the upscaling of the wind speed from the surface air speed measurement to the wind turbine axe level we use a robust power factor.

This remote upscaling factor is defined by also the energy production of a time period.

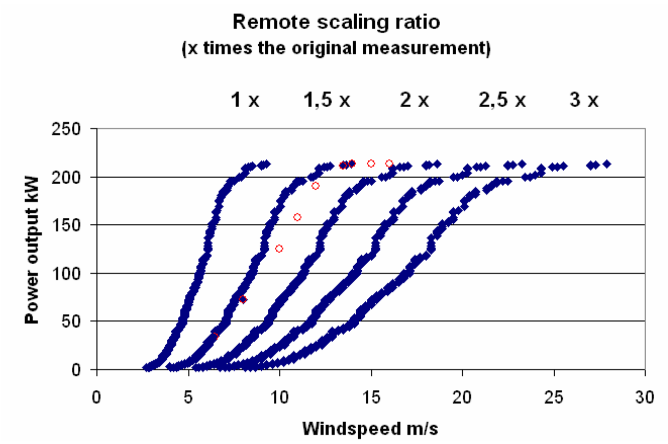

Figure 15
Remote upscaling factor

The Hellmann formula:

$$u_z = u_m \left(\frac{z}{z_m} \right)^a \; [\mathrm{m\,s^{-1}}]$$

$$1{,}7 = (33/10)^{0{,}445} \tag{1}$$

From Figure 15 one can read that in our case (‘Folyás’ -> ‘Bükkaranyos’) the remote upscaling factor is 1,7. It means that in our case in the tower’s 33 m height, the wind speed is 1.7 times greater than the measured speed at 10 m height at ‘Folyás’ meteorological station. Applying the Hellmann equation (1), the exponent is 0,445, that is a good experimental result [8]. We have to mention that our constant upscaling factor is valid for the energy production of a time period. The Hellmann form is generally used for the instantaneous wind speed calculation but it does not take into account the daily fluctuation of the wind speed ratio. It can be modeled by an oscillating exponent.

Conclusion

It is not possible to define the vendor given stationary winds speed–generation characteristics of the wind turbine based on the real-time measurements. The calculations above show that for real-time generation forecast purposes only close measurement/estimation points could be used. The wind forecasts work on worldwide global models, these are theoretically not capable of forecasting local turbulences – which cause the 0.5 - 5 min deviations in the power output. In spite of this fact, based on further measurements quite good energy production estimations can be done. We used the cumulative distribution function to define the ratio between remote wind speed measurement and the possible local wind speed at the turbine.

Acknowledgement

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Figure 16
'Bükkaranyos' V-27 wind turbine

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