Alterations of potential wind energy with height and parts of the day

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Abstract ***According to studies on the planetary boundary layer the theoretical logarithmic wind profile law can give a good approach of wind speed at heights over 100 meters above the ground and at greater heights in periods of close to neutral or weakly unstable atmospheric situations, that is mainly daytime. The value of exponent of simplified version of this law is constant for practical use determined mainly by the roughness of the surface. Due to its simplicity this law is widely used in energetic wind measurements for converting wind speeds measured near the ground to the height of the wind turbines. However the value of the exponent is determined not only by the roughness of the surface, but numerous atmospheric factors like stability conditions, for example, as it was proved by the studies on the wind energy potential of Hungary. For this reason if the diurnal course of the exponent is neglected and a constant value is used for it, the error of the estimation will increase in case of close to the surface inversions (strongly stable conditions) especially in the night. Results of our examinations on the seasonal characteristics of the diurnal courses of the exponent what determines the estimated changes of the wind speed with the height are presented in this paper. Our method is demonstrated on the wind speed datasets of the meteorological tower of Paks for the year of 2000-2001. There are wind speed measurements at three levels (20, 50 and 120 meters) on the tower with the 10 minutes averages registered. On the base of our examinations it can be claimed that there is a turn in the daily course of potential wind energy over the inflexion height that is, there is more utilizable wind energy during the night than in the day. Naturally, the same is true for the electricity produced from wind energy.***

keywords: ***potential wind energy, exponent of Hellman-law, seasonal characteristics of the exponent***

INTRODUCTION

Detailed examinations on the alterations of wind speeds with height was one of the main objectives of the survey of solar and wind energy potential of Hungary. The Hungarian Meteorological Service carried out expedition wind measurements with medium capacity SODAR (*SO*nic *D*etection *A*nd *R*anging) equipment to study wind potential of the country within a frame of a National research and Development Program (*NKFP Report,* 2003, *Dobi* et al., 2006) what can measure the horizontal components (speed and direction) of the wind by sound waves. The equipment can measure the characteristics of air movements directly at 20 different heights between 30 and 315 meters, simultaneously at a given site. Data gained such way can significantly improve the accuracy of the description of a wind profile characteristic for a given location, what has a remarkable significance not just from technical but economic aspect as well. There are numerous publications on the accuracy of SODAR data from the aspect of the examinations on the characteristics of the α exponent in the so called Hellman-equation

$$\frac{v_2}{v_1} = \left(\frac{h_2}{h_1}\right)^{\alpha}, \qquad (1)$$

what describe the alterations of wind speed (this way wind energy) with the height (*Tar*, 2004, *Hunyár* et al., 2004, *Varga,* 2005*, Varga* et al., 2006, *Wantuchné Dobi, I. et al.,* 2005).

Experience gained during the SODAR measurement campaigns carried out in Hungary can be compared to international results (*Vogt-Thomas,* 1995, *Seibert,* 1998, *Mellinghof* et al., 2000, *Baumann-Piringer,* 2001).

In the former studies SODAR data measured in 2003-2004 in Budapest, Paks and Szeged have been analyzed with statistical methods looking for the answer to the question: how does characteristics of the wind change with the height and what factors impact on the direction dependence of wind profiles at given observation sites (*Bíróné Kircsi –Tar,* 2007a, 2007b, *Kircsi-Tar*, 2008, *Tar* et al., 2008)

According to studies on the planetary boundary layer (*Baranka et al,* 2001) theoretical logarithmic wind profile law can give a good approach at heights over 100 meters above the ground and at greater heights in periods of close to neutral or weakly unstable situations, that is mainly daytime. The simplified version of this law for practical use is equation (1) where the value of exponent α is constant determined mainly by the roughness of the surface. According to A*ujeszky* (1949) α=0,2 can give a very good approach up to a height of 250 meters. *Ledács-Kiss* (1977, 1983), *Tóth et al.* (2001), *Patay* (2001a, 2001b, 2003) had used this form of it. However, on the base of meteorological tower and energetic wind measurements the values of α determined by surface friction could be calculated more accurately. According to *Kajor* (2002a, 2002b) its value changes between 0.14 (over smooth sea surface) and 0.34 (over rough land surfaces). According to *Radics* (2004) the value of the exponent is between 0.14 over flat terrain and water bodies, 0.2 over rough, hilly areas and reaches 0.28 over settlements. On the other hand, *Péczely* (1979) had claimed that α is determined not just by surface roughness but wind speeds (its value decreases with increasing wind speeds), and thermal stratification of the atmosphere this way also. According to him, for instance, its value is 0.3 in the case of average wind speeds over grasslands.

Due to its simplicity equation (1) is widely used in energetic wind measurements for converting wind speeds measured near the ground to the height of the wind turbines. However the value of the exponent is determined not only by the roughness of the surface, but numerous atmospheric factors like stability conditions, for example, as it was proved by the studies on the wind energy potential of Hungary. For this reason if the diurnal course of the exponent is neglected and a constant value is used for α, the error of the estimation will increase in case of close to the surface inversions (strongly stable conditions) especially in the night.

Examinations on the daily course of the Hellmann-exponent have a great importance from the aspect of the estimations of daily course of wind speeds for heights different from the standard measurement height. According to the before mentioned studies beyond the roughness, the values of the exponent depend on the atmospheric stability conditions: under stable conditions (in the night) it reaches a high and nearly constant value (0.6-0.7), while under unstable conditions (during the day) it is a function of the temperature with a minimum around 1-2 pm. (0.2-0.3). On the base of its relationship to the diurnal course of the temperature it can be presumed that synoptic conditions have an impact on the characteristics of its diurnal course as well. Therefore it means that its characteristics are determined by air flow types or seasons.

It is interesting from energetic aspects that wind speed have different diurnal courses in the different layers of the atmosphere. It increases from sunrise till its maximum in the early afternoon over a not very rough surface up to a height of 60-80 meters presumably. It has a contrasting behavior at higher levels that is it reaches its minimum in the early afternoon. Naturally, potential wind energy and wind energy utilized in the form of electricity has the same diurnal course. According to our studies (*Tar*, 2006a, 2006b, 2006c, 2007) whole and half day periods of diurnal courses are unreal in only an insignificant ratio of all cases in the two layers. However, it is supposed that there is a so called inflection height at the border of the two layers, where the diurnal course of the wind speed and wind energy is accidental. At that height the amount of wind energy can be constant, what cause much less tasks for electricity network operators. On the other hand, the amount of utilizable wind energy is lower in that layer than at higher levels. (*Bíróné Kircsi –Tar,* 2007a, 2007b, *Kircsi-Tar*, 2008, *Tar* et al., 2008).

Diurnal course of wind speeds and potential wind energy is determined by the height and synoptic conditions. According to the before mentioned facts, there are differences in its values in the different parts of the day: there is more wind energy below the inflection height in the day and over the inflexion height in the night. Results of our examinations on the seasonal characteristics of the diurnal courses of the α exponent what determines the estimated changes of the wind speed with the height are presented in this paper. The before mentioned SODAR measurements were carried out in periods shorter than one year at all the three sites, so they are not suitable for the analyses of seasonal alterations. Our method is demonstrated on the wind speed datasets of the meteorological tower of Paks for the year of 2000-2001. There are wind speed measurements at three levels (20, 50 and 120 meters) on the tower with the 10 minutes averages registered. Dataset were provided by the Hungarian Meteorological Service.

SEASONAL CHARACTERISTICS OF THE ALTERATIONS OF WIND SPEEDS WITH THE HEIGHT

Mean diurnal course of the Hellman-exponent is presented in figure 1 determined from wind speeds measured at different heights for the spring. Its daily mean values are presented for the whole period and for the seasons in table 1. Moving averages in the figure and the values in the table show that the exponent determined from the wind speeds at 20 and 120 meters can be considered as averages of the values calculated from wind speeds measured at the two other heights. The reason for this is that air flows of an atmospheric layer with a height of 100 meters were taken into account presumably. For this reason the most important seasonal characteristics of the α(20/120) exponent are analyzed here.

Table 1: Daily averages of the 10 minutes means of the Hellmann-exponent (α) calculated between the different levels for the seasons and the whole year (Paks, 2000-2001).

	α(20/50)	α(20/120	α(50/120)
Spring	0.49	0.46	0.42
Summer	0.48	0.45	0.43
Autumn	0.48	0.48	0.49
Winter	0.44	0.45	0.45
Annual	0.47	0.46	0.45

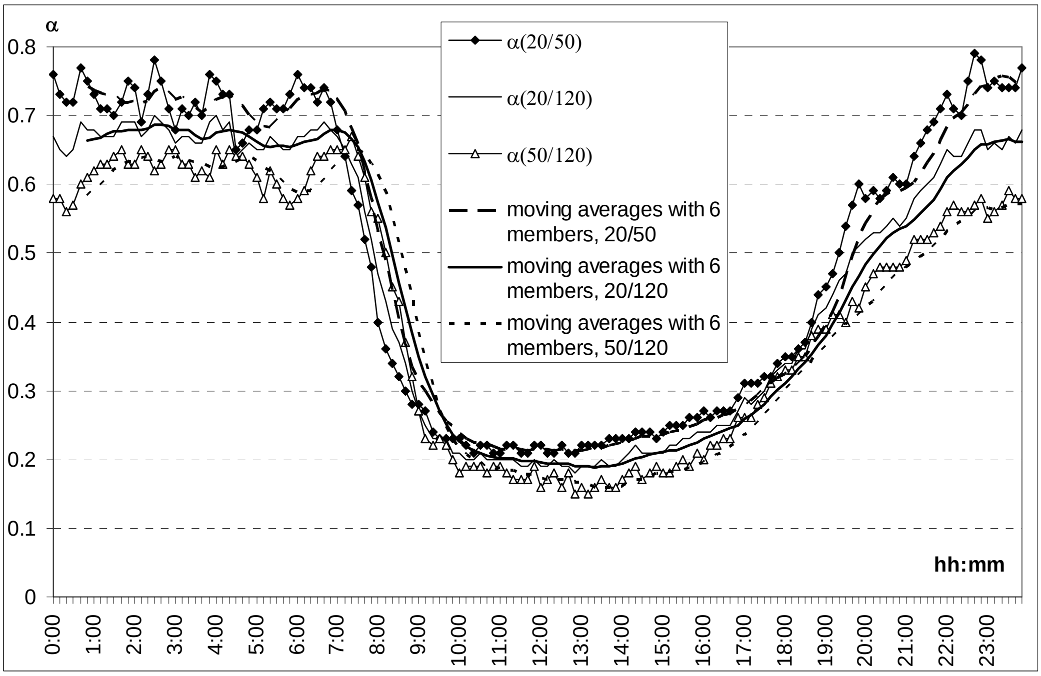

Figure 1: Diurnal courses of the 10 minutes averages of the Hellmann-exponent (α), calculated between the different levels (Paks, 2000-2001 spring).

It can be seen in figure 2 that there are only slight changes in the values of the α(20/120) exponent in the night, dawn and early morning hours; it is over 0.5 for all periods and the whole year. It reaches its minimum in the winter, while its maximum occur in the summer. It is over 0.7 most frequently in the latter period. The values of the exponent start decreasing around 7 pm in the summer, the spring and the whole period, and around 8 pm in the winter and autumn. Minima occur between noon and 2 pm in all periods. Later it increases reaching 0.5 in the spring the earliest around 6 pm but it is over 0.5 after 8 pm in all periods. According to table 2 minima are the lowest in the summer and the highest in the winter, but there are only minor seasonal differences in its minimal values. The amplitude of its fluctuation (maximum-minimum) is the lowest in the winter and the highest in the summer with strong seasonal differences.

Table 2: Daily extremities, fluctuation, average and averages for the parts of the day of the α(20/120) exponent.

	daily			average		
	max.	min.	amplitude	diurnal	day	night
Spring	0.70	0.18	0.52	0.46	0.26	0.63
Summer	0.78	0.17	0.61	0.45	0.22	0.66
Autumn	0.70	0.19	0.51	0.48	0.31	0.63
Winter	0.57	0.23	0.34	0.45	0.35	0.53
Annual.	0.66	0.20	0.46	0.46	0.28	0.61

There are the averages of the studied exponent for the whole day and the parts of the day given in table 2. Presumably, there are not any significant seasonal differences in the daily averages. There is a higher probability of significant differences in the case of the averages for the days (between 9 am and 7 pm) and the nights (between 7 pm and 9 am). Daily averages change between 0.22 and 0.35 in an order of summer, spring, autumn and winter, while it is between 0.53 and 0.66 with an opposite order.

Alterations of the Hellmann-exponent in the seasons and parts of the day should be taken into consideration in the calculation of the wind speeds in the higher layers of the planetary boundary layer by the Hellmann's equation, since errors of those calculations will be multiplied in the calculation of the wind speed cubes that is, the wind power. To determine the daily course of the wind speeds of the higher layers over 60-80 meters (minima around noon) with a good approach can not be used a constant (average) exponent, but the day and the night period should be separated at least, according to the before mentioned issues, since the average exponent is more than three times higher in the summer, one and a half times higher in the winter, two and a half times higher in the spring and two times higher in the autumn than the day time averages of it.

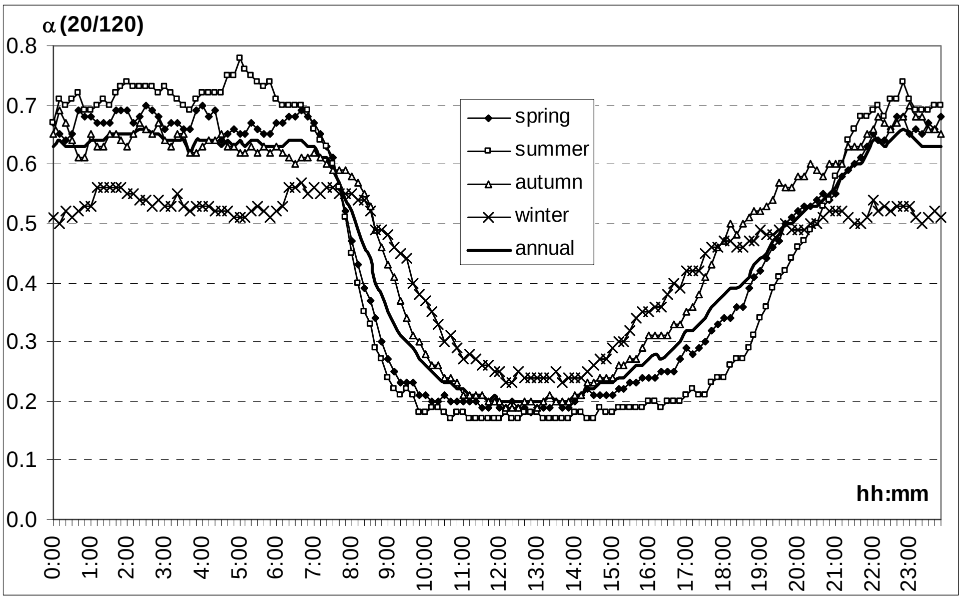

Figure 2: Diurnal courses of the 10 minutes averages of the Hellmann-exponent (α) calculated between the 20 and the 120 meters levels for the seasons and the whole year (Paks, 2000-2001).

CONCLUSIONS

On the base of our examinations it can be claimed that there is a turn in the daily course of potential wind energy over the inflexion height that is, there is more utilizable wind energy during the night than in the day. Naturally, the same is true for the electricity produced from wind energy. Examinations using the wind speed datasets of the tower measurements in Paks had been carried out to prove this hypothesis in our previous studies (*Bíróné Kircsi –Tar,* 2007a, 2007b, *Kircsi-Tar*, 2008, *Tar* et al., 2008). The inflexion height was around 40-50 in the average of the year of 2001. Below that level the daily course had its maxima, while over that level it had its minima around 1 pm. Anyhow, potential wind energy in the day is higher than in the night or equal to it up to a height of only 30 meters according to table 3. The latter one is two times higher at a height of 60-70 meters and more than three and a half times higher at 120 meters than the first one.

There are plans to extend our examinations on the inflexion height and amount of wind energy in the different parts of the day to new sites on the base of SODAR measurements. It can be claimed preliminarily that inflexion height is probably below 80 meters everywhere, therefore over that height the sum of potential wind energy in the night is higher than that is in the day time. Therefore, it raises the question whether it is reasonable to build higher towers for the turbines than the inflexion height till produced electricity can not be stored?

Table 3: Average specific wind power of the day and night hours given in the percentage of the average specific wind power calculated for the whole day (Paks, 2001).

	Day	Night
	%	
20 m	58,2	41,8
30 m	49,1	50,9
40 m	42,7	57,3
50 m	37,9	62,1
60 m	34,1	65,9
70 m	31,0	69,0
80 m	28,5	71,5
90 m	26,5	73,5
100 m	24,7	75,3
110 m	23,1	76,9
120 m	21,8	78,2

ACKNOWLEDGEMENTS

The research project was carried out in the framework of grant program NKTH 3a/0038/2002 “Investigation of the renewable atmospheric energy resources in Hungary, mapping existing potentials and supporting their use with the help of meteorological measurements and forecasts”. Special thanks to the Hungarian Meteorological Service for the coordination of the research activities, and for providing dataset for this study.

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