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Wind profile analyses and atmospheric stability over a complex terrain in southwestern part of Hungary

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Abstract

The sudden and widespread wind technological developments of the last decade raised the question of the effectiveness of wind energy utilisation in moderate wind regions, such as Hungary. In order to support governmental efforts and to facilitate initiatives on renewable energy consumption a research project has started on mapping potential wind resources of the country. The aim of the research presented in this paper is to emphasise the importance of accurate vertical wind profile estimations in wind energy modelling. Wind profile measurements and data analysis are carried out at station Hegyhátsál, where multilevel wind speed time series are available for the 1995–2002 period. The structure of the vertical wind profile, and the atmospheric stability is analysed using the data of four measuring levels (10 m, 48 m, 82 m, and 115 m). Then, estimating vertical cross-sections of wind fields the Wind Atlas Analysis and Application Program (WAsP) has been applied to extrapolate the measured data for the surroundings of station Hegyhátsál.

Keywords: Renewable energy resources; Wind profile; Atmospheric stability; Wind field modelling

1. Introduction

Among renewable energy resources, wind energy utilisation increased the most intensely during the last decade (AWEA, 2002). Furthermore, recent technological developments of wind power generators made it possible to re-evaluate wind energy consumption in continental regions such as the Carpathian Basin. Optimal siting of wind power stations requires proper information on wind profile and atmospheric stability. Therefore, as a part of a Hungarian wind energy research project a case study was carried out on wind profile estimation concerning different stability conditions. Results of this research will be discussed in order to consider and to review the consumption of potential wind energy resources in Hungary.

2. The measuring site

Collaborating with the AEROCARB and CHIOTTO EU-5 framework projects (Haszpra et al., 2001) we had the opportunity to carry out wind profile measurements near the village Hegyhátsál, at a site of the southwestern part of Hungary (46.96°N, 16.65°E). Wind speed and wind direction have been observed at four levels from the end of September 1994 (Bartholy and Radics, 2001) on a 117 m tall TV and radio transmitter tower. The measuring station is situated at 248 m above sea level, and surrounded mainly by agricultural fields and forest patches. As shown in Fig. 1, the lower part of the tower (56 m) is a 7.75 m diameter cylinder where measurements are recorded at 48 m height in both south and north

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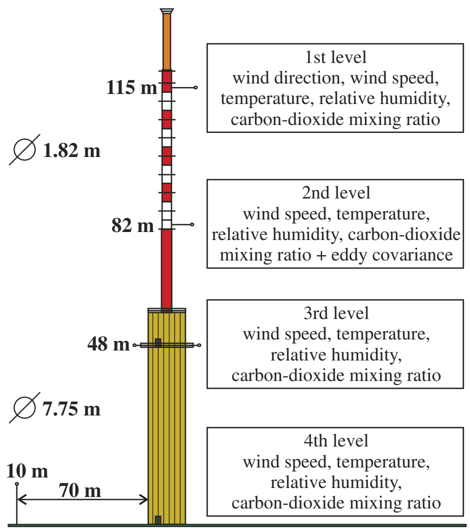

Fig. 1. The layout of the measuring tower and the instrumentation.

direction. On the upper steel cylindrical part (1.82 m diameter) measurements are accomplished at 82 m and 115 m height in north direction. The instrument of the lowest measuring point (10 m) is placed at 70 m away from the tower with the intention to exclude as much as possible shadow effects of the tower. Some human settlements can be found within 10 km, but only small villages with 100–400 inhabitants. The nearest village is about 1 km to the northwest. Over all, the surroundings of the measuring place can be considered as a rural site.

The tower is also a NOAA/CMDL (National Oceanic and Atmospheric Administration–Climate Monitoring and Diagnostics Laboratory) global air sampling network site. In addition to the wind parameters, air temperature, relative humidity, and carbon dioxide mixing ratios are continuously monitored at each level, and the atmosphere-surface exchange of the carbon dioxide is measured by eddy covariance at 82 m height (Haszpra et al., 2001).

3. Data correction

At 48 m height, the large diameter of the tower (7.75 m) cause wind speed distortion which can exceeds 35% of the real wind speed according to the estimations (Barcza, 2001). Therefore, the measured wind speed values are corrected based on the theoretical laminar flow pattern around a cylindrical body. The two components of the horizontal wind speed can be written in the Cartesian coordinate system as

$$u = |v_0|\left\{\cos\varphi_0\left[1-\frac{R^2}{r^2}\cos 2(\varphi_0-\varphi)\right] -\frac{R^2}{r^2}\sin\varphi_0\sin 2(\varphi_0-\varphi)\right\},$$

$$v = |v_0|\left\{\sin\varphi_0\left[1-\frac{R^2}{r^2}\cos 2(\varphi_0-\varphi)\right] +\frac{R^2}{r^2}\cos\varphi_0\sin 2(\varphi_0-\varphi)\right\},$$

where v_0 is the undisturbed wind speed, φ_0 is the angle of the wind vector, R is the radius of the cylinder, r and φ are polar coordinates of the point of interest (Nagy, 1989). The x and y axes of the Cartesian coordinate system points towards east and north, respectively.

Since tower-induced von Kármán vortices distort the average wind vector in the downwind direction, only the measured value of the anemometer located on the upwind site is used for the reconstruction of the wind speed:

$$v_0 = \frac{v_{48}}{\sqrt{1-2\frac{R^2}{r^2}\cos 2(\varphi_0-\varphi_b)+\frac{R^4}{r^4}}},$$

where v_{48} is the wind speed value measured by the anemometer located on the upwind site, φ_b is the angle of the boom (90° and 270° for the northern and southern anemometer, respectively).

The shadow effect of the measuring tower is much less at 82 m and at 115 m height, where the radius of tower is considerable smaller (1.82 m) than at 48 m (Fig. 1). Therefore the same procedure is applied at those levels without distinguishing between more and less disturbed signal of the anemometers (Barcza, 2001).

4. Wind profile estimations and stability conditions

Multilevel wind speed measuring experiments on towers are one of the most suitable tools to estimate the vertical profiles of wind speed. Although our data set includes errors caused by the shelter and wind field perturbation effects of the specially shaped tower, detailed profile analysis and profile fitting can provide appropriate information about the vertical structure of the air flow.

Eight-year-long (1995–2002) time series of station Hegyhátsál were used for the analysis presented here. Relative frequencies of measured wind speeds at different observation levels are demonstrated on Fig. 2. Relative frequencies of calm periods are between 3.1% (at 82 m) and 5.6% (at 10 m) that are relatively low compared to some other regions of Hungary. The most frequent wind speed values are in the 2–3 m s^{-1} interval at both levels. Relative frequencies of larger wind speed intervals are significantly increasing with height above the ground.

Next, wind energy utilisation of the country was analysed for the transitional seasons when annual maximum and minimum values occur. Using the monthly averaged wind speed data of the last eight years (1995–2002) of