LATVIAN JOURNAL OF PHYSICS AND TECHNICAL SCIENCES
2016, N 3

DOI: 10.1515/lpts-2016-0016

PHYSICAL AND TECHNICAL ENERGY PROBLEMS

INVESTIGATIONS OF WIND SHEAR DISTRIBUTION ON THE BALTIC SHORE OF LATVIA

V. Bezrukovs[1, 2], A. Zacepins[1], Vl. Bezrukovs[2], V. Komashilovs[1]

[1]Institute of Physical Energetics, 21 Aizkraukles Str.,
Riga, LV-1006, LATVIA
[2]Ventspils University College, 101 Inzenieru Str.,
Ventspils, LV-3601, LATVIA
e-mail: elmag@inbox.lv

The paper presents a review of wind parameter measurement complexes and investigation methods used for potential wind energy evaluation. Based on results of long-term investigations of wind shear distribution regularities are shown up to 160 m height on the Baltic Sea shore. Distribution of potential wind energy in Latvia is shown as a map and table of average and average cubic wind speed values. Database of wind parameter measurements is available at a public website.

Key words: *website, wind map, wind shear, wind speed measurement.*

1. INTRODUCTION

When designing wind power plants (WPPs), one of the main criteria for evaluating the commercial use of wind energy is availability of reliable information on the force of wind streams and their distribution in height. Investigations show that for the countries of the Baltic region it is typical that the wind turbines (WTs) work inefficiently at the height below 100 m [1]. The results of direct measurements of the wind speed for corresponding heights at the site of WPP construction are very valuable while estimating the expected recoupment terms for the relevant WPP developing projects.

Continuous perfection of the design for wind power generators is conducive to their operational efficiency, which means shorter recoupment terms for the costs of building the WPPs. Therefore, in Latvia under wide discussion there are the issues of attraction of investments – both at the state level and in the business environment – for WPP building.

2. METHODS OF WIND ENERGY FLOW INVESTIGATION

In most cases, for wind speed measurements the measuring sensors are employed whose mounting on a 50–60 m high mast is simple enough, or it is possible to use the masts for cellular communications [2], [3] disposed at a small distance from the WPP building site. Depending on landscape this distance should not exceed 2–4 km.

Wind energy potential evaluation on height of 24 m was performed using the Symphonie measurement complex during construction of the first WPP in Ainazi (Latvia) in 1994. This WPP consisted of two WTs with power of 600 kW [4]. Later on for wind shear investigations, mobile measurement sensors NRG #40 and NRG #200 were used for recording of wind speed and wind direction. Sensors were mounted on 50–60 m high masts in Ventspils district Irbene (site 1) and in Matishi (site 2) [1].

As a main recorder in the measurement system, LOGGER Symphonie 9200 is used, which performs recording of wind speed, wind direction and ambient temperature indicators with interval of 3 seconds. Afterwards the recorder performs averaging of obtained data for 10-min intervals and stores the results on the SD card, which can be used for further analysis. The unit is powered by two 1.5 V batteries, whose capacity is enough for 4–5 month of interruptible system operation.

Figures 1 – 5 demonstrate the registration unit LOGGER Symphonie 9200 and sensors for wind speed NRG #40 (S), wind direction NRG #200, temperature NRG #110s and air pressure NRG BR-20 measurements, which are mounted on metal mast at a height of 60 m.

Fig. 1. Registration unit LOGGER Symphonie 9200 for recoding data from sensors of wind speed NRG #40, vane NRG #200, temperature NRG #110s and air pressure NRG BR-20.

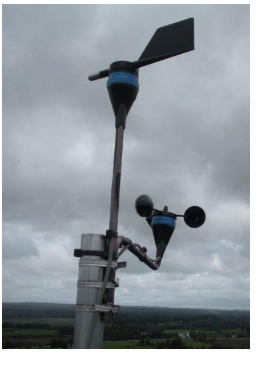

Fig. 2. Sensors for wind speed NRG #40, vane NRG #200, which are mounted on mast.

For wind energy estimation at a height up to 200 m optical remote sensing complexes with Light Detection and Ranging (LIDAR) technologies ZephIR and Pentalum SpiDAR were used.

Complex ZephIR (Fig. 6) was installed on the balcony of floor 8 of Ventspils College building (site 3) located 800 m from sea shore within the framework of FP7 project “NORSEWInD” [5].

Fig. 3. Temperature sensors NRG #110s.

Fig. 4. Air pressure sensor NRG BR-20.

Fig. 5. Installation of the 60-m high mast with a measuring complex Symphonie 9200 together with sensors on metal 1.8-m long mounting boom (site 2).

Fig. 6. Optical remote sensing complex ZephIR for measuring wind speed and direction at a distance up to height of 160 m on five height levels (located in Ventspils, site 3).

Figure 7 demonstrates laser measuring complex Pentalum SpiDAR, which was installed in the territory of Ventspils International Radio Astronomy Centre at the height of 13.2 m above ground level and at a distance of 2.5 km from the sea shore on a platform with coordinates N 57º33′12.00″ and E 21º51′16.00″ (site 4).

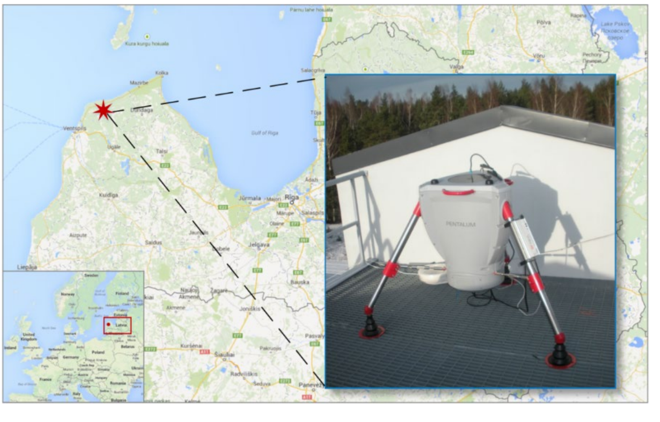

Fig. 7. Laser measuring complex Pentalum SpiDAR installed on the Baltic Sea shore at a height of 13.2 m above ground (site 4).

For the data transmission an optical communication line was employed which connects the measuring complex with server at Ventspils University College. The Pentalum SpiDAR performed 5 s measurements of wind speed and direction for ten height levels: 30, 40, 50, 80, 100, 120, 140, 160, 180 and 200 m. Apart from that, the records were made for pressure, humidity, and temperature of the air.

3. THE RESULTS OF WIND SHEAR INVESTIGATION

As a result of systematic, long-term measurements and evaluations of wind energy in Latvia, a huge amount of statistical data was collected for wind shear investigation on the Baltic Sea shore in Ventspils and Ainazi regions.

From the analysis of the statistical data reported in [5], [6], it follows that the curve of the average long-term wind speed distribution at height $V_{avg.h}$ is well approximated by the power law function:

$$V_{avg.h} = V_{avg.ref} \left(\frac{h}{h_{ref} - h_0}\right)^{\alpha}, \quad (1)$$

where $V_{avg.ref}$ is the value of the average long-term wind speed at the height of measurement h_{ref}, h_0 – height of the forest and α is the approximation coefficient.

Similarly, to approximate the curve of height distribution for the average cubic long-term wind speed values $V_{avg.cub.h}$ the following expression could be used:

$$V_{avg.cub.h} = V_{avg.ref} \left(\frac{h}{h_{ref} - h_0}\right)^{\beta}, \quad (2)$$

where $V_{avg.cub.ref}$ is the value of the average cubic long-term wind speed at the height of measurement h_{ref}, and β is the respective approximation coefficient.

Figures 8 and 9 display, respectively, the curves of height h distribution for the average long-term wind speed values $V_{avg.h}$ and the curve of such distribution for the average cubic long-term wind speed values $V_{avg.cub.h}$. For wind shear modelling up to the height of 190 m expressions (1) and (2) are used on the basis of measurement data and extrapolation coefficients, which for Site 1 can be expressed as equations (3) and (4) [7]:

$$V_{avg} = 1.09 \cdot (h-10)^{0.39} \text{ (m/s)}, \quad (3)$$

$$V_{avg.\,cub} = 1.80 \cdot (h-10)^{0.30}, \quad (4)$$

and for Site 2 as equations (5), (6):

$$V_{avg} = 1.06 \cdot h^{0.36} \text{ (m/s)}, \quad (5)$$

$$V_{avg.cub} = 1.72 \cdot h^{0.29} \text{ (m/s)}. \quad (6)$$

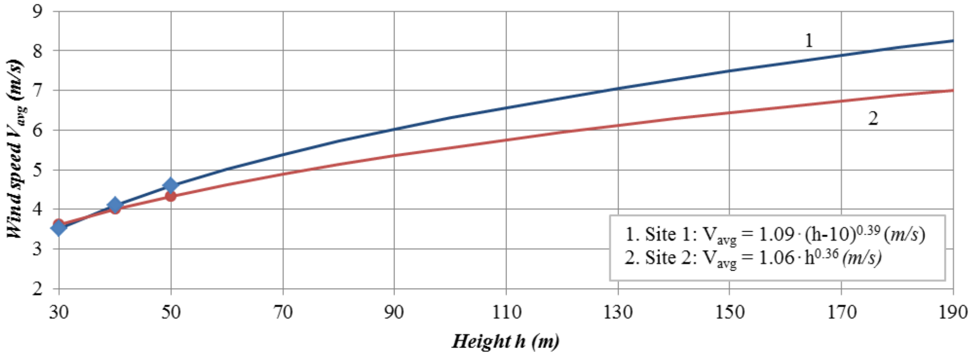

Fig. 8. The average long-term wind speed vs. height, $V_{avg.h} = f(h)$, for the sites 1, where h_0 = 10 *m*, and 2 extrapolated for the height up to 190 m using power law relationship (3), (5).

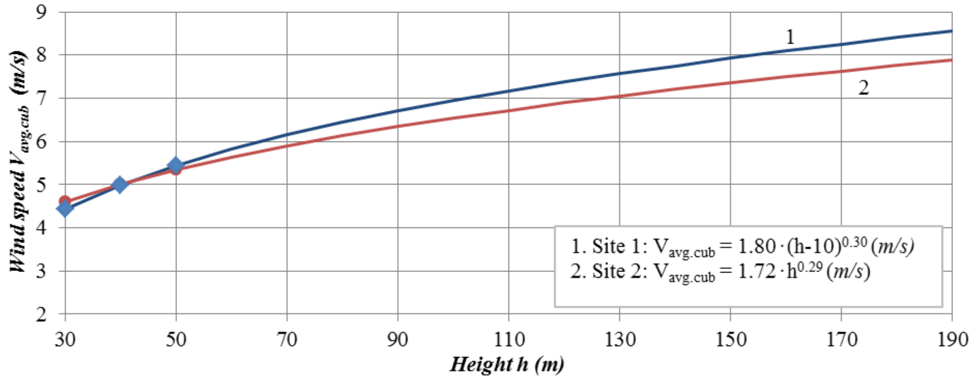

Fig. 9. The average long-term wind speed *vs.* height, $V_{avg.cub.h} = f(h)$, for the sites 1, where h_0 = 10 *(m)*, and 2, extrapolated for the height up to 190 m using power law relationships (4) and (6).

4. MAP OF POTENTIAL WIND ENERGY DENSITY IN LATVIA

Since 1945, systematic long-term wind speed measurement results at a height of 10 m have been stored in the archive of the Latvian Environment, Geology and Meteorology Centre. There are 24 sites, where wind speed monitoring takes place.

Distribution pattern of the average values of wind speeds in Latvia, obtained by analysing and summarising those long-term measurements, is presented in papers [8]–[10] in the form of different maps.

Based on these research materials about wind flow distribution and long-term wind shear investigations using measurement complexes at height up to 200 m, the authors developed the wind map shown in Fig. 10. This version of wind map allows for visual representation of wind speed distribution in Latvia divided into four zones I, II, III and IV, where different colours correspond to the different wind shear profiles.

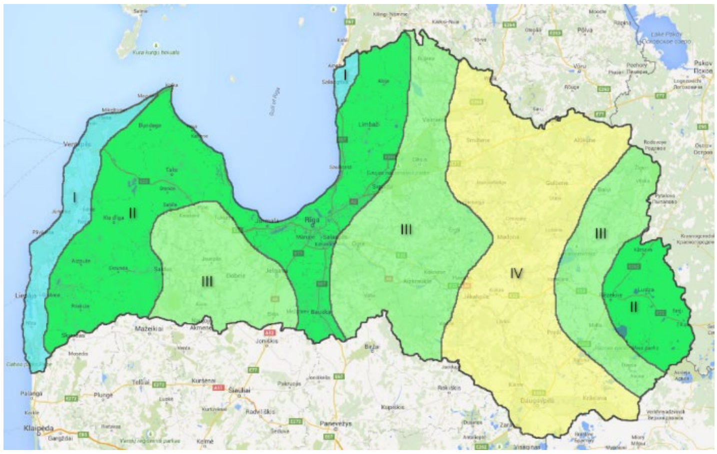

Fig. 10. Map for visual evaluation of distribution potential wind energy density in Latvia, where colours show regions with different average wind speed values V_{avg}, *(m/s).*

Tables 1 and 2 show average $V_{avg,}$ and average cubic $V_{avg\ cub}$ wind speed values at height of 30, 50, 100, 120, 140 and 160 m.

Value of average wind speed V_{avg} is calculated by expression

$$V_{avg} = 1/n \sum_{i=1}^{n} (V_i), \tag{7}$$

where V_i – wind speed value (m/s) for one measurement time (for measurement complex Symphonie – (3–5) s);

i = 1, 2, 3...n – count of measurements.

Value of average cubic wind speed $V_{avg.cub}$ is calculated by expressions

$$V_{avg.cub} = \frac{1}{T} \sqrt[3]{\sum_{i=1}^{n} (V_i T_i)^3} \tag{8}$$

where V_i – wind speed value (m/s) for one measurement time;

T_i – measurement time (s);

i = 1, 2, 3...n – count of measurements;

T – total measurement time, which is equal to sum of all measurements, calculated by expression

$$T = \sum_{i=1}^{n} T_i. \tag{9}$$

Table 1

Average Wind Speed V_{avg} Values for 4 Zones in Latvia at Heights h of 30, 50, 100, 120, 140 and 160 m

Zone	*h, m*	30	50	100	120	140	160
I	V_{avg}, *m/s*	3.6	4.6	6.3	6.8	7.3	7.7
II		3.5	4.5	5.7	5.9	6.3	6.8
III		3.4	4.0	4.9	5.2	5.5	5.7
IV		3.2	3.8	4.7	4.9	5.2	5.4

Table 2

Average Cubic Wind Speed $V_{avg.cub}$ Values for 4 Zones in Latvia at Heights h of 30, 50, 100, 120, 140 and 160 m

Zone	*h, m*	30	50	100	120	140	160
I	$V_{avg\ cub}$, *m/s*	4.7	5.5	7.1	7.5	7.9	8.2
II		4.6	5.3	6.5	6.9	7.2	7.5
III		4.5	5.1	6	6.3	6.5	6.7
IV		4.3	4.9	5.7	6.0	6.2	6.4

Values from Table 2 can be used for evaluation of wind flow energy intensity and calculation of wind turbine efficiency if installing them at different heights in different zones [11].

Within the ESF project a publicly available website (https://latwinddata.venta.lv/) has been developed for detailed visualisation of the collected wind data. Users can find basic information (average, min, max wind speed values per day) for the whole measured period, as well as the wind speed distribution curves are shown [12].

This website is dedicated for educational and research purposes allowing users to derive detailed information of wind parameters easily. In the future, it is planned to add wind data from other wind measurement devices and systems.

5. CONCLUSIONS

1. Results of long-term wind speed measurements using met masts of 50–60 m with registration unit LOGGER Symphonie 9200 and LIDAR complexes are presented on the map with four regions I, II, III and IV with different annual average wind speed values.
2. Results of wind shear measurements that are presented on the map are summarised in tables with values of average and average cubic wind speeds at heights of 30, 50, 100, 120, 140 and 160 m for each zone.
3. Publicly available website has been developed, where users can find basic information (average, min, max wind speed values per day) for the whole measured period, as well as the wind speed distribution curves are shown.

ACKNOWLEDGEMENTS

The research has been supported by the State Research Program "LAT-ENERGI".

REFERENCES

1. Shipkovs P., Bezrukovs V., Bezrukovs Vl., Pugachevs V., and Silutins V. (2011). Measurements of the wind energy resource in Latvia. *World Renewable Energy Congress WREC 2011*, Sweden, 8–13 May 2011, Linköping, 0724 WE.
2. Bezrukovs V., Bezrukovs Vl., Shipkovs P., and Lizuma L. (2013). Investigation of wind energy distribution in height in Latvia. In *Proceedings of the 2013 ISES Solar World Congress*. Cancun, Mexico, 3–7 November 2013.

3. Bezrukovs, V., Bezrukovs, Vl., and Levins N. (2011). Problems in assessment of wind energy potential and acoustic noise distribution when designing wind power plants. *The 52nd International Scientific Conference on Power and Electrical Engineering*. Riga Technical University, October, 2011.
4. Bezrukov, V., Domburs, L., Pugachev ,V. (1995). The performance evaluation of the efficiency of the TW 600 wind power converter in Ainazi region. *Latvian Journal of Physical and Technical Sciences*, 2, 35–45.
5. Bezrukovs, V., Bezrukovs, Vl. (2012). Wind speed and energy at different heights on the Latvian shore of the Baltic Sea. *WREF 2012*, Denver, Colorado. Available at https://ases.conference-services.net/resources/252/2859/pdf/SOLAR2012_0214_full%20paper.pdf
6. Bezrukovs, V., Bezrukovs, Vl., and Lizuma, L. (2014). The landscape influence on the wind energy distribution in height on the Latvian shore of the Baltic Sea. *Energy Procedia*, 52, 223–233.
7. Bezrukovs, V., Zacepins, A., Bezrukovs, Vl., and Komashilovs, V. (2015). Assessment of wind shear and wind energy potential in Latvia. *Latvian Journal of Physics and Technical Sciences* 2, 26–39.
8. Vēja karte un kvalitāte. Available at http://www.kerveju.lv/veja_karte.php
9. Vēja ātrums 10 metru augstumā. Available at http://www.windenergy.lv/karte.html
10. Ostapenko J., and Gamalejevs A. (2004). Latvijas vēja enerģijas rokasgrāmata.
11. Bezrukovs, V., Bezrukovs, V., and Zacepins, A. (2014). Comparative efficiency of wind turbines with different heights of rotor hubs: Performance evaluation for Latvia. *Journal of Physics*: Conference Series 524 (2014) 012113, pp. 1–9.
12. Komashilovs V., Zacepins A., Bezrukovs V., Bezrukovs D., and Hofmanis J. (2014). Web application for processing and analysis of the raw wind measurement data. In *Proceedings of 15th IEEE International Symposium on Computational Intelligence and Informatics* (CINTI 2014), 19–21 November 2014, Budapest, Hungary, pp. 455–458.

VĒJA VERTIKĀLĀ PROFILA SADALĪJUMA PĒTĪJUMI BALTIJAS JŪRAS KRASTĀ

V. Bezrukovs, A. Zacepins, Vl. Bezrukovs, V. Komašilovs

K o p s a v i l k u m s

Rakstā ir dots apskats par vēja parametru mērīšanas kompleksiem un izpētes metodēm, kuri ir izmantoti dažādās vietās Latvijā ar mērķi novērtēt vēja enerģijas potenciālu. Balstoties uz ilglaicīgiem vēja vertikālā profila sadalījuma pētījumiem Baltijas jūras krastā, vēja ātruma sadalījuma likumsakarības ir demonstrētas līdz 160 metru augstumam. Rakstā ir prezentēti koeficienti, kuri ir lietoti vēja vertikālā profila ekstrapolācijai pēc jaudas likuma. Iespējamais vēja enerģijas sadalījums Latvijā ir parādīts kartes formā un tabulā ar vidējām kubiskām vēja ātruma vērtībām. Vēja parametru mērīšanas datubāze ir publiski pieejama tīmekļa vietnē.

04.03.2016.