ANALYSIS OF WIND POWER FLOW ON DIFFERENT HEIGHTS IN VENTSPILS REGION BASED ON MEASUREMENTS BY PENTALUM SPIDAR

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Abstract. Nowadays energy issues and energy independence topics, including renewable energy sources, are widely discussed on local Latvian and EU level. Wind energy is one of the alternative energy sources which is fast-growing and is sustainable in long-term perspective. One of the main requirements for wind energy sector development and wind farm building is availability of reliable information about wind energy distribution in the region for a long time period and prediction of wind turbine energy production with smallest possible uncertainty. In this paper analysis of wind shear on heights up to 200 m for different time scales is performed. Conclusions are made about diurnal, monthly and seasonal variations of wind power distribution and possible energy production based on one-year wind measurements data. Wind measurements are done using wind measurement complex Pentalum SpiDAR, which is located on-shore in Ventspils region, Latvia during a one-year period from 03.2014 to 03.2015. To have realistic calculated numbers for potential power production power curves of several types of WT with rated power from 50 to 3000 kW are used. Additionally, an analysis of the diurnal variation of energy production is made to evaluate the possibility of using wind turbines as one of the main sources of energy in the region. As well, publicly available website is developed for visualisation of the collected wind data, showing basic information for the whole measured period (average, min, max values per day) and demonstrating wind speed distribution curves. This website is dedicated for educational and research purposes allowing easily derive detailed information of wind parameters.

Keywords: wind energy; long-term wind measurements; wind shear analysis; lidar wind measurements.

Introduction

Wind energy is one of the alternative energy sources which is fast-growing and is sustainable in long-term perspective. In Latvia there is also interest to wind energy production and there is potential for building wind farms [1]. A main prerequisite for wind energy development and management is the availability of accurate and reliable information about wind conditions (speed and distribution) in the area to estimate the potential of wind turbines in the specific geographical location [2]. To evaluate the potential of wind turbines wind parameters at the height where the rotor hub can operate are needed to be known. State meteorological stations measure wind on heights up to 20 m, which is usually not enough to precisely estimate the wind energy potential in that region. Modern high power wind turbines operate in heights more than 100 m, and to measure wind at these heights expensive devices, such as Lidar, can be used. Another option is to measure wind parameters at heights (up to 60-80 m) using cheaper equipment, like metrological masts equipped with cap anemometers and model wind parameters for heights up to 200 m using Weibull or Rayleigh approaches [3;4]. Using the Lidar real wind parameters are measured, but using different modelling methods the results will be with some error and will not show the exact real values.

In this paper analysis of diurnal, monthly and seasonal wind power density distribution at different heights in Ventspils region based on lidar measurements is presented.

The measured wind parameters are collected using Pentalum SpiDAR (see Figure 1), which is located in Irbene, Latvia (see Figure 2). Pentalum SpiDAR measures the wind speed and direction and stores the raw and average values obtained within 10 minutes interval. The data are automatically stored in built-in ftp server. Afterwards the data files are uploaded to the application server and parsed in the developed system fully automatically [5]. The wind measurement period is one year from 2014.03.01 to 2015.03.01, data analysis is made by different periods (day, month and season), the wind bin is 1 $m \cdot s^{-1}$, lidar quality threshold is 20. The quality is determined based on percentage of raw results used to calculate 10 minutes average and the relationship between the current measurement and measurements in neighbouring heights and times. Signal or equipment problems leading to quality = 0.

In the paper the height above the ground level is considered as the height reference system. The measurement site is located on 16 m height above the sea level.

Fig. 1. **Pentalum SpiDAR located in Irbene, Latvia**

Fig. 2. **Site location of measurement place on shore of the Baltic sea in Latvia**

All collected data are summarised and visualised using the developed web application for processing and analysis of the raw wind measurement data [5]. These data on heights 30-200 m are used to calculate the potential power production. To have realistic calculated numbers for potential power production power curves of several types of WT with rated power from 50 to 3000 kW are used (http://pdf.directindustry.com/pdf/enercon/enercon-product-overview/20877-243513.html).

Analysis of wind speed measurements

The wind speed in Ventspils region in Latvia is not so huge comparing to other world regions, but still it should be enough for usage of wind turbines. Figure 3 demonstrates the calculated values for average wind speed for the whole measurement period (one year). Analysing average wind speed values it can be seen that increase in wind speed by height is almost linear, when the R^2 coefficient (square of the correlation coefficient) is equal to 0.9908. As well, the power law can be used to describe these values, when the R^2 coefficient is equal to 0.999. Comparing to long-term measurements the curve of average wind speed is similar, but the absolute values can differ up to 5-10 %.

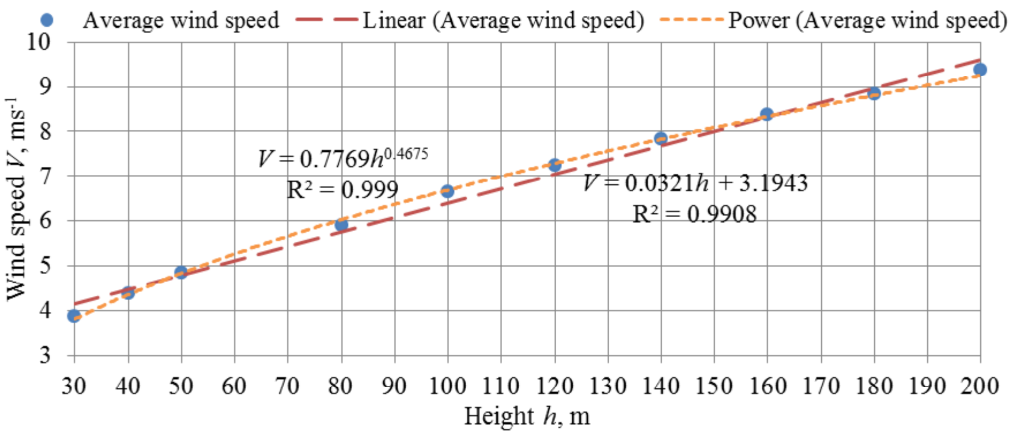

Fig. 3. **Average wind speed for 03.2014-03.2015 with linear and power models**

An important aspect while analysing wind parameters is the wind speed frequency distribution by height, which is used also for calculation of the potential power production. The wind speed frequency distribution shows how much time (percent of time) different wind speeds occurred during the whole measurement period. The measured wind frequency distribution together with the power curve of wind turbine Enercon E-82 with rated power 2300 kW is shown in Fig. 4.

The column chart below (see Figure 5) summarizes wind speed distributions and demonstrates the amount of time when the chosen intervals of wind speed occurred. Analysing the wind speed frequency distribution it can be concluded that on 30 m height the wind speed is mainly distributed (more than 95 % of time) from 0 to 8 $m \cdot s^{-1}$, on 80 m from 0 to 10 $m \cdot s^{-1}$ and only on 200 m from 0 to 15 $m \cdot s^{-1}$. Effectiveness of the wind turbine at heights to 100 m is limited by a long period of time of the wind speed from 0 to 3 $m \cdot s^{-1}$ and lack of wind speed more than 13 $m \cdot s^{-1}$. For example, on 30 m height the wind speed from 0 to 3 $m \cdot s^{-1}$ is occurring up to 35 % of the total time, and the wind speed more than 13 $m \cdot s^{-1}$ is not occurring at all.

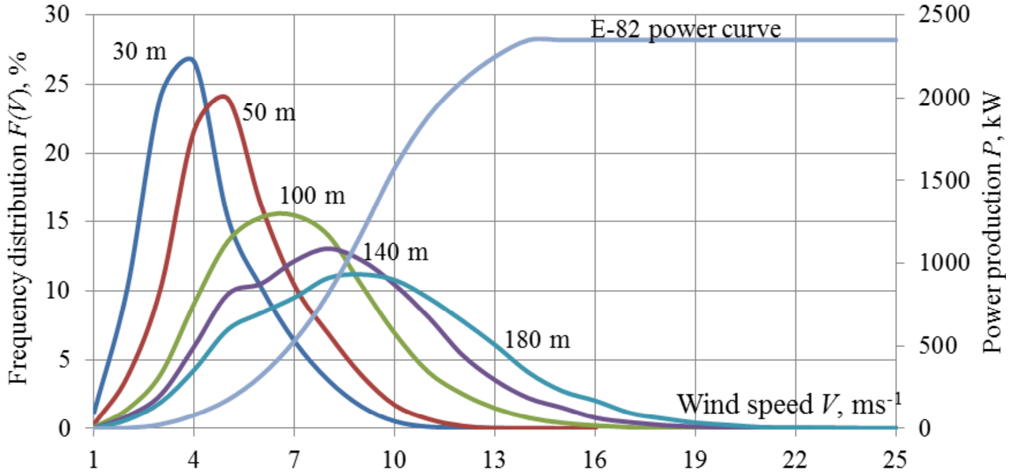

Fig. 4. **Wind speed frequency distribution for period 03.2014-03.2015 with power curve of wind turbine Enercon E-82 with rated power 2300 kW**

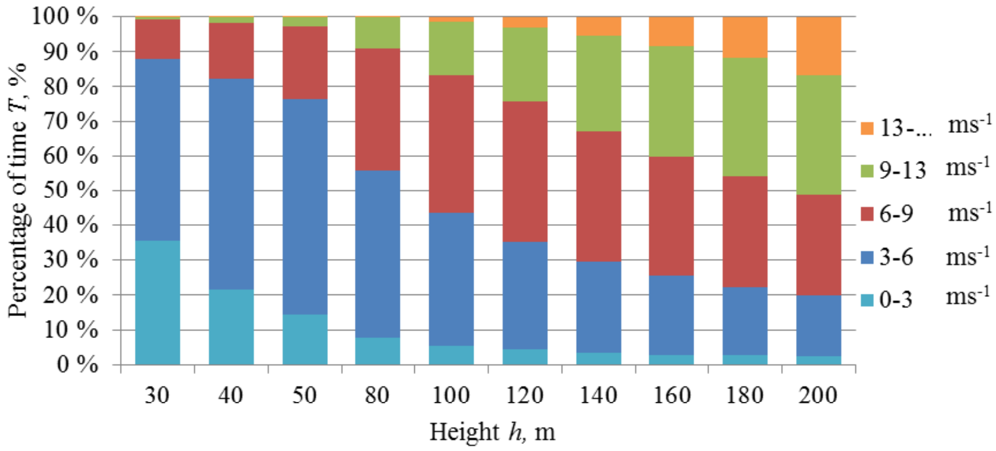

Fig. 5. **Relative time duration T, % of air flow with wind speed in intervals 0-3, 3-6, 6-9,9-13, 13 -... $m \cdot s^{-1}$ up to height of 200 m for one year measurement period**

It is a known fact that wind speed is not constant in different time periods; it differs by months, weeks and even by days. Figure 6 demonstrates the measured average wind speed summarised by month for the whole year. One can see that with increase of height fluctuations in average monthly wind speed becomes more significant.

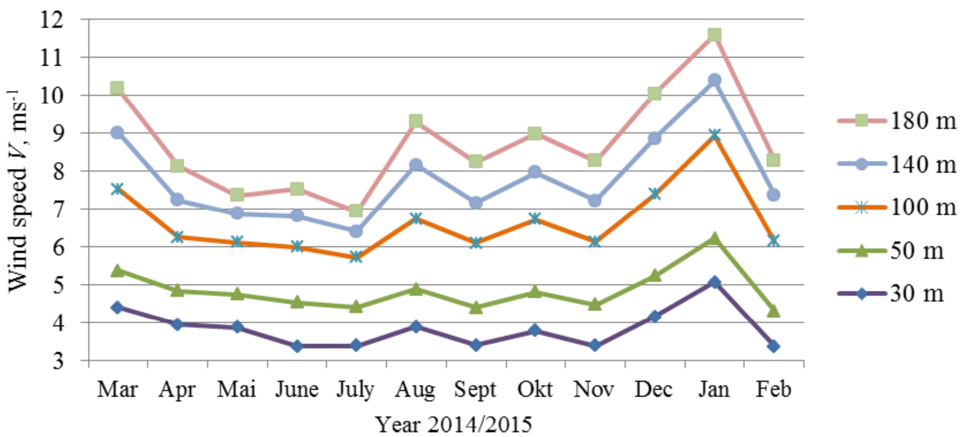

Fig. 6. **Average wind speed by month for one year period from 03.2014 to 03.2015**

Evaluation and comparison of wind power production in different time periods

When the wind parameters are measured and known, it is possible to calculate and evaluate the potential power production. As it was already mentioned, calculation of the potential power production is based on the power curve of the wind turbine Enercon E-82. Power is calculated by multiplying the power of the wind turbine of the corresponding wind speed with time, when this wind speed is occurring. The potential power production on heights 100, 140 and 180 m is analysed and compared.

Comparison by seasons

Potential power production is compared between different seasons of the year: spring, summer, autumn and winter. The charts below (Figure 7-9) show wind speed frequency distributions during the mentioned seasons at three different heights.

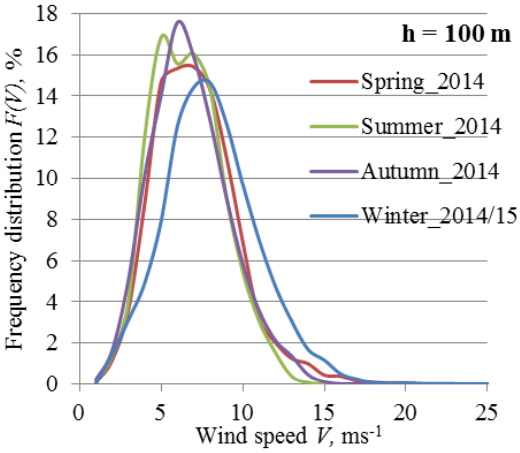

Fig. 3. **Seasonal wind speed frequency distribution at 100 m height**

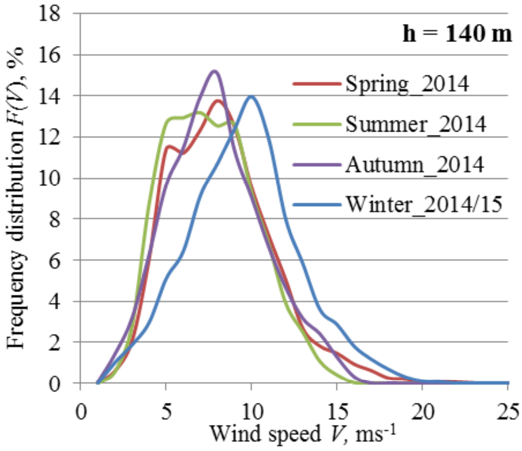

Fig. 4. **Seasonal wind speed frequency distribution at 140 m height**

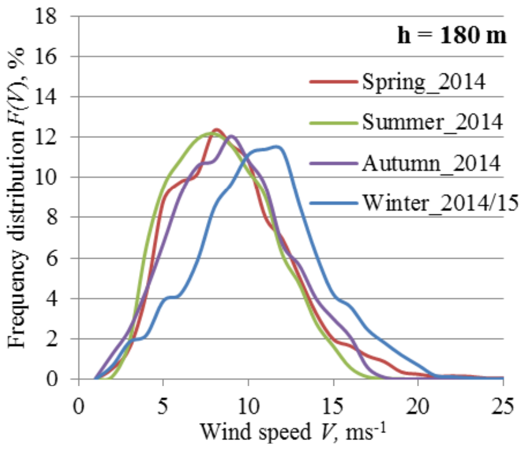

Fig. 5. **Seasonal wind speed frequency distribution at 180 m height**

The next chart summarises the power production and its differences in all seasons (see Figure 10). The whole year power production is considered as 100 %, and it can be seen that in winter approximately 1/3 of all wind power is produced. It can be concluded, that the difference in the potential power production between seasons can be more than 10 %.

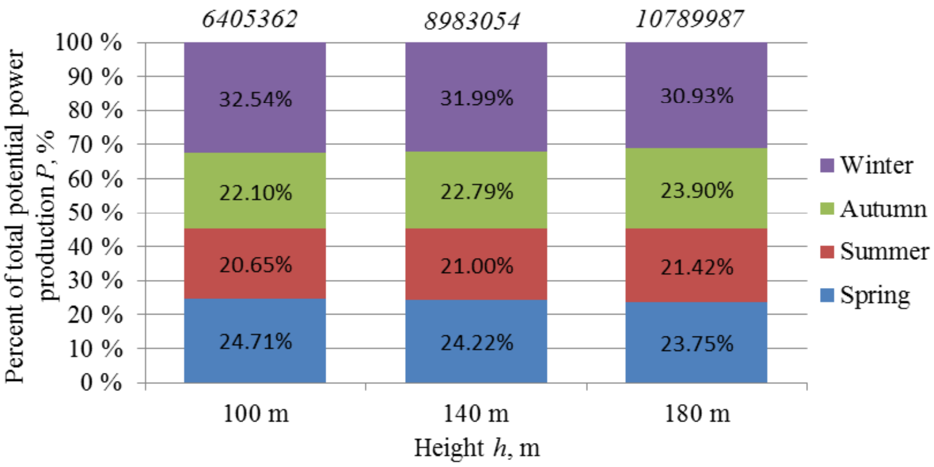

Fig. 10. **Distribution of potential power production by seasons at 100, 140, 180 m heights**

Comparison by months

Potential power production per month and percentage of monthly potentially produced power as a part of the whole power production is shown below (see Figure 11-12):

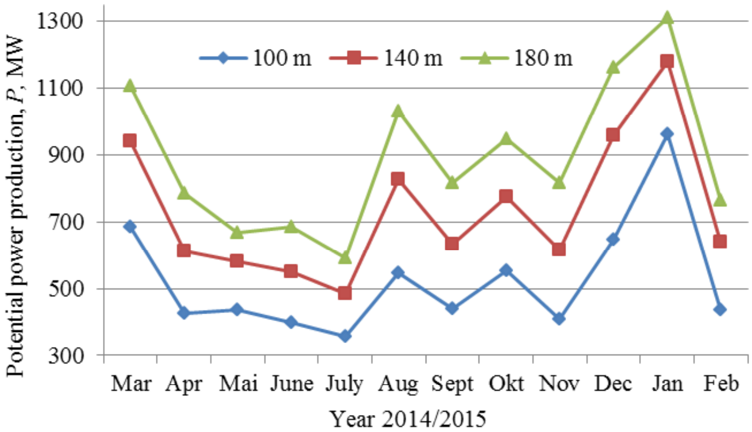

Fig. 11. **Average potentially produced power in each month**

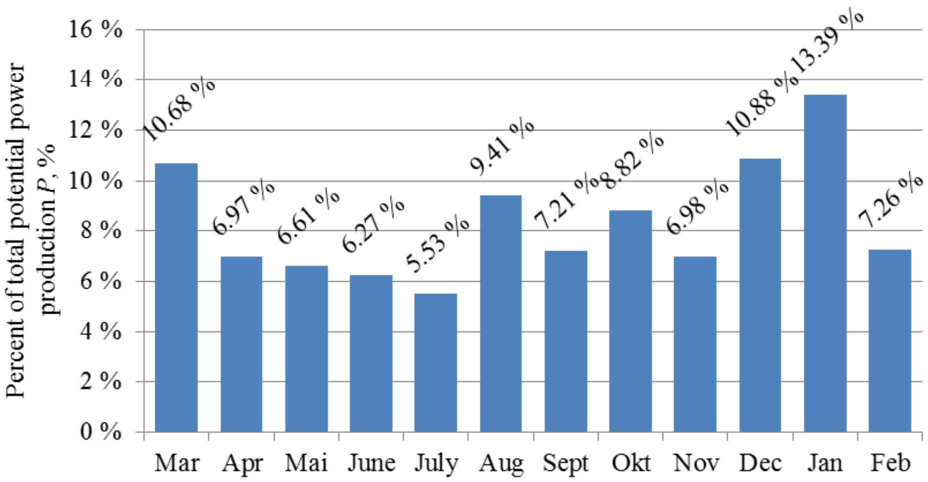

Fig. 12. **Distribution of potential power production by months at 140 m height**

It can be concluded that power production can differ very dramatically in different months, for example, the difference between the produced wind power in July at 140 m is twice less comparing to March. This can be observed also by analysing *min* and *max* values per month, it is seen that *max* values is almost doubled *min* value.

This analysis and numbers confirm the fact that prediction of wind power cannot be made by knowing the wind parameters in a short period of time (period of one or three months), it is needed to evaluate the wind conditions in long-term perspective. Is it assumed that a period of one year should be enough for approximate prediction of wind power production.

Comparison by days

One more interesting and important thing is comparison of the potential power production measured by days. Height 140 m is used for demonstration (see Figure 13). It can be concluded that the difference between power production by days also is significant. It can be observed that the difference between windy days and windless can be up to 80 %.

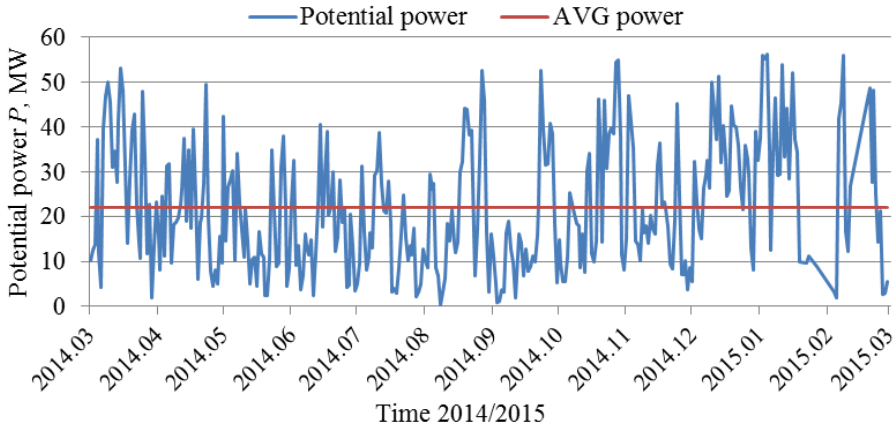

Fig. 13. **Distribution of potential power production by days at 140 m height (period 2014.03.01-2015.03.01)**

Evaluation of annual energy production

During this research also the potential annual energy production (*AEP)* was calculated and evaluated at different heights based on different wind turbines. Turbines with corresponding hub height were taken to complete this analysis. Table 1 shows the potential *AEP*, MWh and the WT coefficient of efficiency C_e, %. *AEP* of the WT is calculated based on equation 1:

$$AEP = \sum \left(P(V_i) \cdot F(V_i) \right), \tag{1}$$

where the values of function $P(V_i)$ are corresponding to the power curve for the generator, while those of function $P(V_i)$ – to the wind speed frequency distribution.

At estimation of the *AEP* (calculated for each WT type) with respect to its maximum that can be obtained from generators for one year period (8760 hours) of their uninterrupted operation with the rated power (P_r) the efficiency of a particular WT can be expressed as:

$$C_e = \frac{AEP}{P_r \cdot 8760}. \tag{2}$$

Table 1

Potential *AEP*, MWh and WT coefficient of efficiency C_e, % for different heights

Height, m	***AEP*, MWh**	**Max *AEP*, MWh**	**C_e, %**	**Type of WT**	**P_r, kW**
30	56	438	12.78	E-3120	50
40	82	438	18.62	E-3120	50
50	106	438	24.21	E-3120	50
80	4711	26280	17.93	E-82	3000
100	9098	26280	34.62	E-101	3000
120	10976	26280	41.76	E-101	3000

Analysis of the results, achieved by the measurements for the period of time 01.03.2014-01.03.2015, shows that under conditions characteristic for the distribution of the wind energy potential in the Latvian territory commercial use of WT is possible if the hub height is more than 50 m.

For example, to raise the operational efficiency of WT E-3120, it is necessary to increase the height of the rotor hub from 30 to 50 m, this will increase the efficiency from 12.78 % to 24.21 %, and at 120 m height the efficiency of WT can achieve 41.76 %, but it can be considered as extreme value, that is not typical for Latvian conditions.

Within the project a publicly available website (https://latwinddata.venta.lv/) is developed for detailed visualisation of the collected wind data. Users can see 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. This website is dedicated to educational and research purposes allowing derive detailed information of wind parameters easily. In the future it is planned to add wind data from other wind measurement devices and systems.

Conclusions

1. The paper presents results of wind shear measurements up to 200 m height using the measuring complex Pentalum SpiDAR.
2. Based on the analysis results in the time period from 01.03.2014 to 01.03.2015 diurnal, monthly and seasonal potential wind power fluctuations are shown.
3. Comparison of the potential power production by seasons shows that almost 1/3 of the year power is potentially produced in the winter season.
4. Effectiveness of wind turbine at heights to 100 m is limited by a long period of time of the wind speed from 0 to 3 $m \cdot s^{-1}$ and lack of the wind speed more than 13 $m \cdot s^{-1}$.
5. It is shown that changing the height of the rotor hub from 30 to 50 m, the WT efficiency increases from 12.78 % to 24.21 %.
6. At 120 m height the efficiency of WT can achieve 41.76 %, which is not typical for Latvian conditions.

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