JOURNAL OF ENVIRONMENTAL ENGINEERING AND LANDSCAPE MANAGEMENT
ISSN 1648-6897 print/ISSN 1822-4199 online
2013 Volume 21(3): 209–215
doi:10.3846/16486897.2013.800078

INVESTIGATION OF THE WIND CHARACTERISTICS AND PROSPECTS OF WIND POWER USE IN LITHUANIA

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Submitted 12 Dec. 2012; accepted 24 Apr. 2013

Abstract. This paper addresses the current situation and future prospects of the use of wind energy in Lithuania. Furthermore, it investigates wind power resources. During the last ten years, assessment of wind power resources was carried out, wind characteristics measurements were made, observation data of Lithuanian meteorological stations were collected and these data were generalized. Measurements have shown that the most suitable and promising region for installation of wind turbines and wind farms in Lithuania is the coastal area of the Baltic Sea. The suitability of several existing wind turbine sites was evaluated according to the variation of the capacity factor C_p, which describes the efficiency of installed wind turbines. Global trends in the development of the power sector reveal the prevalence of wind power installations. The increase in the use of wind energy not only reduces environmental pollution, but also creates new jobs in rural areas and decreases dependence on fossil fuels. The aim of this work is to present the current situation of wind energy development and the results of the investigation of wind climate conditions in Lithuania. The investigations demonstrated good prospects for wind power utilization at the coastal area of the Baltic Sea, as well as possibilities to install wind turbines on the continental part of Lithuania.

Keywords: wind, resources, measurement, wind turbines, power, capacity factor, output, efficiency.

Reference to this paper should be made as follows: Katinas, V.; Sankauskas, D.; Perednis, E.; Vaitiekūnas, P. 2013. Investigation of the wind characteristics and prospects of wind power use in Lithuania, *Journal of Environmental Engineering and Landscape Management* 21(3): 209–215. http://dx.doi.org/10.3846/16486897.2013.800078

Introduction

Wind power's share of total installed power capacity over the last decade has increased more than fourfold from 2.2% in 2000 to 10.5% in 2011. Over the same period, renewable capacity increased by a third from 22.5% in 2000 to 31.1% in 2011. The twenty-first century sees the EU power sector moving away from fuel oil, coal and nuclear, while continuing to increase its total installed capacity with gas, wind and solar PV to meet increasing demand. The development of wind power generation is observable in many countries.

In 2011, 9616 PubMed MW of wind energy capacity was installed in the EU, making a total of 93,957 MW – enough to supply 6.3% of the EU's electricity, according to figures published today by the European Wind Energy Association (EWEA).

In Lithuania, the first 0.63 MW wind turbine (WT) was installed near Vydmantai on the coastal zone of the Baltic Sea in 2004. In 2006, WT installation increased and the company "Vejo spektras" installed the first 30 MW WT farm near Kretinga (Katinas, Markevičius 2006; Markevičius *et al.* 2007). Another company "Renerga" installed the WT farm with capacity of 16 MW at the start of 2007. Afterward, installation of single large-scale commercial WTs with the capacity of 0.6 MW and WT farms intensified at different sites of our country. At the end of 2011, Lithuania's installed capacity of WTs totalled 179 MW. Obviously, there is an evident increase in the development of wind energy in Lithuania just as in other world countries (Cadenas, Rivera 2007; Xia, Song 2009; Saidur *et al.* 2010).

This growth, together with the foreseeable installation of many wind farms in the near future, forces the utilities to evaluate diverse aspects of the integration of wind power generation in power systems (Lew 2000; Varun *et al.* 2009). It is evident that wind energy resources and possibilities of their utilization vary from country to country; therefore, experiences of separate countries cannot be mechanically transferred (Baltrėnas *et al.* 2004; Katinas *et al.* 2008; Leung, Yang 2012).

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The possibility of wind energy use in Lithuania was performed by local and foreign researchers (Rathmann 2003; Katinas *et al.* 2008). Obviously, even on the scale of Lithuania the universal way, applicable for all regions equally is absent. It depends on local natural conditions, on energy infrastructure development level of the region, on population demand for energy resources and a series of other factors (Marmidis *et al.* 2008; Ahmed *et al.* 2010). Implementing wind energy is associated with great investments; therefore wind power utilization may be initiated only after investigations of wind flow characteristics on the WT sites and economical aspects of wind energy production (Lu *et al.* 2002; Ahmed 2012; Durišic, Mikulovič 2012).

Wind energy, in contrast to fossil fuels and nuclear power, do not pollute our atmosphere with greenhouse gases, nor do they cause any problems for future generations with radioactive waste. Thus, wind power though considered environmentally benign, still imposes some impacts on human life (Leung, Yang 2012). However, the impacts of wind turbines on our environment have not been well established and remain under debate.

In this paper, we present recent data on installed wind power capacity and generation depending on the place of installation of wind turbines (WT). Also, there are given data on wind characteristics and the information about prospects of the possibility of use of wind energy in Lithuania.

1. Methodology

The information about distribution of wind energy parameters is an important factor to estimate wind energy potential for the location of wind turbines. Regular measurements of wind velocities and directions have been performed in Lithuanian meteorological stations that are distributed in a fairly regular network over the whole country. Wind velocities are also measured in airports, seaports and in some other sites. For more precise assessment of wind climate conditions in the coastal region of Lithuania, wind energy parameters measurements were performed near the Baltic Sea in Giruliai (region of Klaipeda). All data were generalized and wind energy resources assessment was carried out.

1.1. Experimental measurement method

Wind parameters measurement equipment "WICOM-C", made in Germany, was positioned at 1.5 km distance from the Baltic Sea in Giruliai, on a hill at 24 m height over the sea level. Its coordinates: 21°10′ East longitude and 55°43′ North latitude. Here wind parameters (wind velocity, wind direction, etc.) were measured every 10 seconds, integrated and every 10 minutes fed into the computer memory. Also, the data logger carried out calculation of standard deviation of velocity at all measurement heights for each interval. Measurements of wind velocity were carried out in four heights above ground level: 10, 30, 50 and 65 m. Measurements of wind directions were performed at a height of 30 m from ground level with accuracy 1°. Wind characteristics were measured and analysed during the time period from 1995 to 2012.

1.2. Theoretical models for analysis of experimental data

The corresponding theoretical models were applied for the statistical analysis of the measured wind characteristics, as well as the model for analysing vertical profile of the wind velocity. A methodology for estimation of the annual production of electrical energy for the selected wind turbines has also been presented in Section 2.2.

Actually, wind velocity continually changes its direction and magnitude, and hence wind energy $E(t)$ also varies continually. There are Weibull and Rayleigh probability distribution functions, which can be used to describe the wind velocity data (Altunkaynak *et al.* 2012). Weibull is a two-parameter function, while Rayleigh is one-parameter function. Moreover Weibull probability distribution function is more versatile and Rayleigh distribution function is simpler to use. Under assumption that wind velocity is described by random stationary t – function wind energy may be expressed as (Omer 2008; Chang 2011):

$$E = \frac{1}{2}\rho \int_0^\infty f(V)V^3 dV, \quad (1)$$

where $f(V)$ is velocity probability distribution density function.

It can be summed from wind velocity histograms that approximating probabilities distribution density must have expressed maximum value within the limits of 4 to 6 meters per second and positive asymmetry (Fig. 1). For evaluation of these conditions Weibull distribution probability density function is most suitable (Rathmann 2003):

$$f(V) = \frac{k}{a^k} V^{k-1} e^{-(V/a)^k} = kAV^{k-1}e^{-AV^k}. \quad (2)$$

Accordingly Weibull distribution function is described by

$$F(V) = 1 - e^{-(V/a)^k} = 1 - e^{-AV^k}, \quad (3)$$

where $A = 1/a^k$, V is the monthly mean wind velocity, k is a dimensionless shape factor, which indicates wind velocity stability and is related to the variance of the wind velocity,

Where a is scale parameter (with units of velocity) related to the mean value of wind velocity. Higher value of a indicated that wind velocity for that

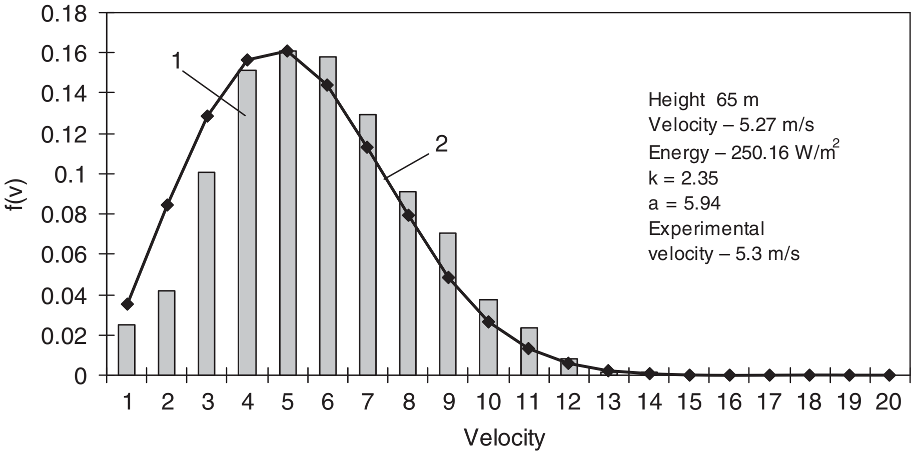

Fig. 1. Weibull distribution of wind velocity variations and estimated parameters k and a at 65 m height above ground level in Klaipeda region (Giruliai): 1 – experimental data; 2 – approximation by Weibull distribution function

particular month was higher. Parameters a and k were calculated using least squares method. Having Weibull distribution parameters a and k we can find main magnitudes, which describe random value of wind velocity at various heights over the surface of the ground.

We shall use following formulas for calculation of wind energy parameters: for energy

$$E = 1/2\ \rho a^3\ \Gamma(1 + 3/k)\,(W/m^2), \tag{4}$$

where Γ is gamma function of Euler. Average velocity

$$V = a\Gamma(1 + 1/k)\ (m/s). \tag{5}$$

With the assumption that probability distribution concerning V_{n1} and V_{n2} belongs to the same type of Weibull distribution, we obtain that, link between parameters (a_{n1}, k_{n1}) and (a_{n2}, k_{n2}) at heights h_1 and h_2 over ground level, correspondingly is:

$$a_2 = \alpha a_1^{\beta},\ k_2 = k_1/\beta; \tag{6}$$

$$\alpha = (h_2/h_1)^{B_0},\ \beta = 1 + B_1\ \mathrm{In}(h_2/h_1), \tag{7}$$

where on the basis of experimental measurement data

$$B_0 = 0.37\ and\ B_1 = -0.088.$$

2. Results and discussion

2.1. Analysis of wind characteristics

Data gathered by Lithuanian meteorological stations in the period of 1977–1986 were used for calculation of wind power resources in the Lithuanian territory. Data obtained show that the greatest wind power resources are in the Baltic coastal region (Klaipeda) and in the peninsula Kursiu Nerija (Nida), where average wind velocity at 10 meters above ground surface is more than 5 m/s (Fig. 2). However, investigation shows that the coastal region (Klaipeda) is the most suitable one for construction of wind turbines, particularly its 10 km wide coastal strip. Kursiu Nerija (Curonian Spit) with its greatest wind velocities is not suitable for this purpose as environmental requirements do not allow the use of this territory for installing industrial facilities, because the territory constitutes a National Park, which was set up in 1991. In the bigger of territory of Lithuania average wind velocity is considerably lower than in the coastal region; nevertheless, there are areas, where wind velocities are sufficient for building wind power plants.

Wind energy parameter measurement in the coastal region of the Baltic Sea (Giruliai) shows that wind velocities here are sufficiently high (Fig. 3). In the period of 1995–2003 annual average wind velocity at 50 meters altitude was 6.4 m/s. In Lithuania the greatest wind velocity was from October to February, while the lowest wind speed was observed from April to July.

Wind variation during every 24 hours is uniform enough, with velocity profile at the same hour for all days of the month being the same. For example, the

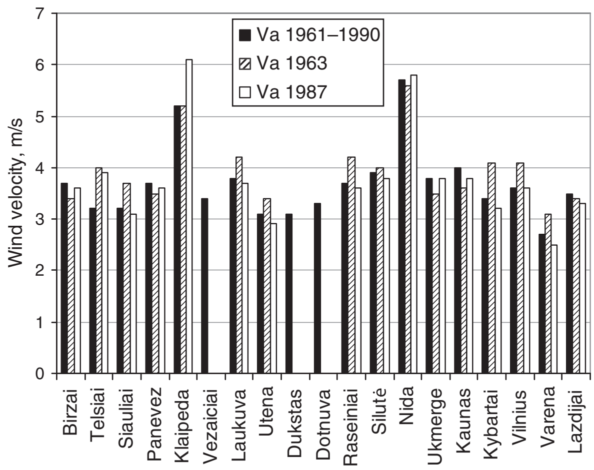

Fig. 2. The average wind velocity in the sites of Lithuanian meteorological stations at 10 m height above ground level for different time measurement periods

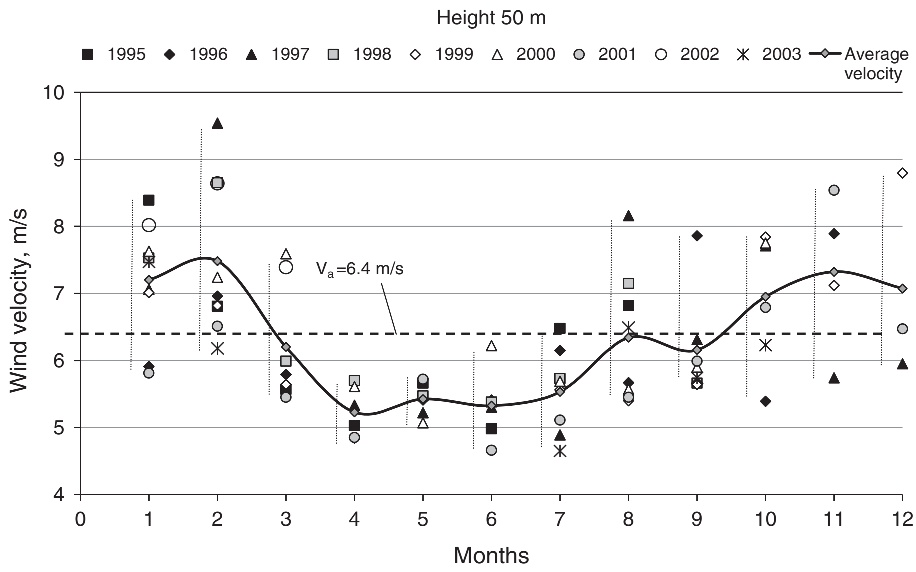

Fig. 3. Annual variation of average monthly wind velocity in the Baltic coastal region (Giruliai) at 50 meters height above ground level

data of Figure 4 does not show any big changes in average wind velocity per day from 1 to 24 hours for a period of one month.

The terrain roughness, atmospheric mixing following a daily cycle driven by solar heating, and the hub height of the wind turbine are the main factors effecting wind flow velocity change. However, the range of variation between night and day typically diminishes as hub height increases. At a height of approximately 50 meters, it weakens or may even disappear in some cases (Fig. 4).

Terrain roughness affects the velocity of the wind closer to the ground. In areas with a high degree of roughness, such as forests or cities, near-surface wind flow velocity tends to be low and wind shear high, whereas the converse is true in areas of low roughness, such as flat open fields. For each hour, the average square wind velocity value is defined by standard deviation. Standard deviation is calculated using formula:

$$\sigma = \left[\frac{\sum_{1}^{n} (\bar{V} - v_i)^2}{(n-1)} \right]^{0,5}, \tag{8}$$

where: $\bar{V}$ is average wind velocity; v_i is instant value of it; n is number of measurements within one time interval.

Distribution profiles differ significantly for maximum and minimum monthly average wind velocities. We see that wind velocity profile varies little if wind velocities are maximal during 24 hours. Prevailing wind direction is from northwest (Fig. 5). We can see that greatest wind speeds occur in winter and lowest in summer. The analysis of data shows that at greatest wind velocity west direction prevails and at lowest wind velocity east direction prevails, that is, winds blow from the continent side.

Hence, to use wind energy in a most efficient way, it is expedient to build wind power plants as near the

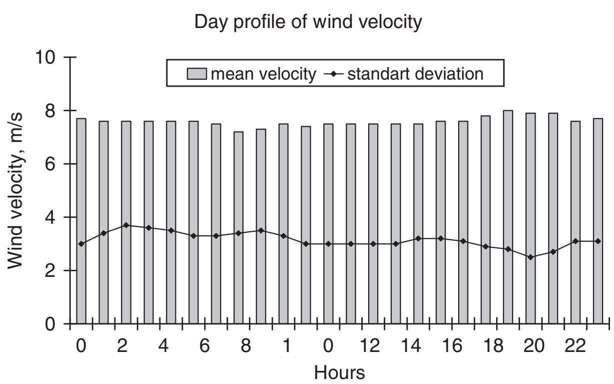

Fig. 4. Day profile of wind velocity in Giruliai at 50 m height above ground level

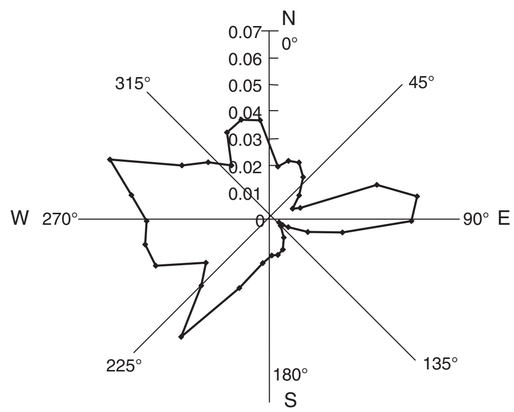

Fig. 5. Distribution of wind directions at 30 m height above ground level during a month in Giruliai

sea as possible, even in the sea, if possible. In such case, we would have the least influence of rough terrain on reducing velocity of the wind. Because maximum wind velocities prevail in winter with little variation during 24 hours, we can use wind power application for buildings heating. In summer, when wind velocities are smaller, wind power may be used for household needs such as lifting water into reservoirs and farming. It would be very efficient to implement the wind power in practice. While planning construction of the wind power plants, environmental, urban, free land and other problems as well, must be taken into account (Varun *et al.* 2009). Most components of the wind power plants as WT rotor, tower, plant nacelle, foundation and electronic control equipment may be manufactured in Lithuania.

2.2. Evaluation of efficiency of installed wind turbines

The efficiency of WT was evaluated according to the annual average wind velocity, which value intensively varies during the observation time. There are intensive changes of wind velocity during the year, month, day and other shorter periods, as well as hourly time, minute, and so on. During the operation time the nominal capacity of WT cannot be used, because there are intervals of time with low wind velocities.

The suitability of WT site was evaluated by capacity factor of WT, which was calculated from equation (Acker *et al.* 2007; Yang *et al.* 2012):

$$C_p = \frac{E_m}{E_{om}}, \tag{9}$$

where: E_m is the real output of energy of WT in the test site; E_{om} is the possible output of energy of WT at nominal capacity.

The possible monthly output of WT is calculated by:

$$E_{om} = P_n \cdot N_m, \tag{10}$$

where: P_n is nominal power; N_m is number of hours in the month.

The analysis of output of WT was done near the Baltic Sea and in the continental part of Lithuania (Fig. 6). Power capacity factor, of WT installed near Vydmantai 630 kW capacity, was $C_p = 0.265$. WT used 26.5% of all nominal installed capacity per year. The use capacity for small-scale WT (capacity 0.25 MW and less), installed in the coastal area of the Baltic Sea and in the continental part of Lithuania, was markedly lower than a large-scale one. It depends on the climate conditions of selected site for the WT installation. Usually the small-scale WTs are installed near houses, where roughness of terrain is big and they have the tower at lesser height. The investigation of climate conditions of installed WT in Lithuania apparently showed that the choice of the installation of WT sites must be better as they collected for installed WT. Worldwide experience shows, that it is possible to use up to 40% of nominal capacity of installed WT and more.

In the coastal area of the Baltic Sea of Lithuania, according to investigation of climate conditions, it is possible to use about 30% of nominal capacity of WT per year, but attention for the selection to WT installation sites (Boccard 2009) must be increased. The analysis of wind data suggests a feasible prospect for electricity generation from wind energy resources in Lithuania.

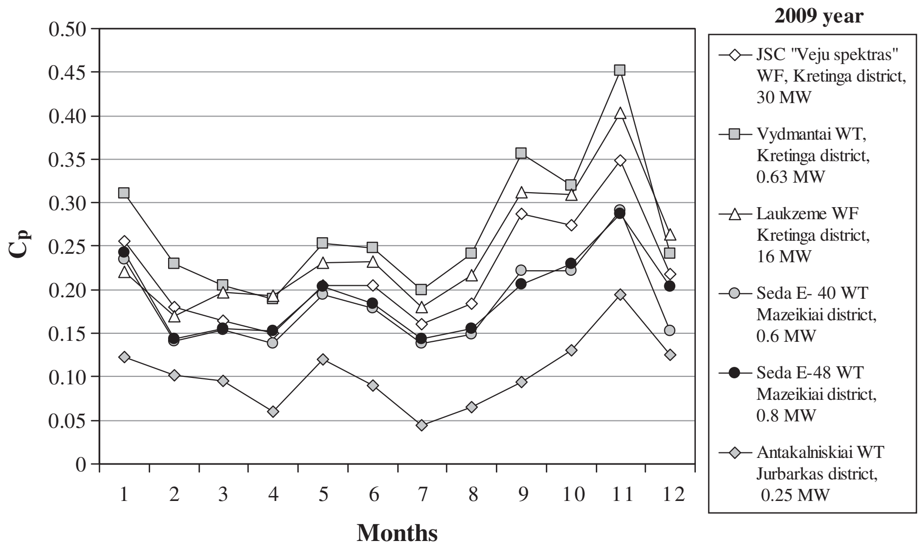

Fig. 6. Variation of capacity factor C_p of separate wind turbines (WT) and wind farms (WF), operating in different regions of Lithuania

Conclusions

1. Analysis of wind flow energy characteristics is carried out using annual observation data of Lithuanian meteorological stations and wind velocity and direction measuring data. The measurements of wind parameters of LEI were carried out for the long period in Giruliai, employing state-of-the-art wind parameters measurement equipment *"Wicom-C"*. The data were used for optimal selection of sites for WT installation, a type of WT, to calculate electricity output and to forecast the more effective utilization of wind energy resources.

2. The simulation model is proposed for assessment of the potential of wind power generation at a location. It is found that the hub height of a wind turbine is an important parameter in power generation. Equations (6) and (7) can be used for the evaluation of the output of WT dependent on the tower height.

3. The analysis of the energy output of single WT and wind farms located at different distances from the Baltic Sea has shown that mean annual capacity factor C_p of the WT installed in the coastal area of the Baltic Sea reaches about 0.265. The value of C_p for the WT installed in the continental part of the country is considerably lower.

4. The highest wind velocities are in winter (from October to February) and the lowest winds are in summer (from April to July). This annual profile of wind velocity is convenient from the production point, because electrical energy consumption in winter is higher than during summer.

5. Investigation shows that the coastal area of the Baltic Sea is the most suitable and perspective region for installation of wind turbines, particularly its 10 km wide strip. The climatic and topographic conditions of the sites have influence on the output of WT and therefore, WT site selection must be done more thoroughly in Lithuania.

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