WIND POWER STATIONS PERFORMANCE ANALYSIS AND POWER OUTPUT PROGNOSIS

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Abstract. Historically the first wind power devices were used directly for some specific task e.g. grain grinding, flour milling, water pumping and similar. Nowadays, the wind power mills are mainly used to produce the most effective energy type – electric energy that is easy to transfer to other necessary energy types with comparatively good efficiency coefficient. Substantial problems in this case originate from the stochastic nature of the wind energy that is hard to forecast. The longer period weather observations show that there are however some similarities in different years' winds at the same months. The definite correlation exists between the air pressure variation speed and wind strength though the prediction of the air pressure variation speed is also complicated. Contrary, the wind speed variation range can be determined with adequate accuracy and usually also the wind speed distribution in given observation point. That makes possible the prediction of energy production in given place during some period. For that it is necessary though to know the power curve of the wind turbine used.

Key words: wind speed, wind speed distribution, wind turbine power curve, wind turbine hourly output, energy quantity produced.

The wind speeds and wind energy utilization in Estonia

From the point of view of wind speeds and so their usability for electric energy production the territory of Estonia may be divided in two main parts: the Western and Northern coast areas and islands where the yearly average wind speed is 4...7 m/s and inland areas with average wind speed less than 4 m/s. The average wind speeds higher than 4 m/s are measured also at the largest lakes and their shores – Peipsi and Võrtsjärve [1]. Table 1 gives the overview of the wind energy systems development and wind energy utilization in Estonia in recent years.

Table 1

The wind energy utilization in Estonia [2]

Year	2003	2004	2005	2006	2007
Electric energy production, GW·h	10 159	10 304	10 205	9731	12 139
From that, wind electricity, GW·h	6.1	7.6	53.9	76.3	95.7
Wind electricity in %	0.060	0.074	0.530	0.780	0.750
Wind turbines installed power, MW	2.4	22.4	31.0	31.0	51.8

These wind turbines are installed mostly at the wind-parks on the sea shores and the islands (Viru-Nigula – 24 MW, Pakri I – 18.4 MW, Rõuste – 8 MW, Läätsa – 3 MW, Virtsu I – 1.8 MW, Nasva – 1.6 MW) and some of them as separate units. Only one wind turbine of accountable power (0.5 MW) is installed inland and belongs to Sangla Turvas company (Southern Estonia, Tartu County) [3].

Besides these there are some small-power wind turbines in different places over the country installed by enthusiasts and used to produce electric energy only for individual consumers (owners) mostly for heating purposes.

There are also a number of wind-park projects under development with the total installed power up to 400 MW. The largest of these are Päite-Vaivina wind-park (63 MW), Pakri II wind-park (50.6 MW), Purtse wind-park (50 MW), the wind-park of Baltic Power Station II ashes field (50 MW), Aulepa wind-park (40 MW) and so on.

In longer perspective the wind-parks on the sea shores, at open sea and Peipsi Lake are planned with total installed power up to 2000 MW.

At the same time it is necessary to take into account that because of the wind gustiness, the electrical output of the wind turbines can fluctuate in wide ranges (0…90 % of installed power). In these conditions to guarantee undisturbed electricity supply for the consumers, it is necessary to have additional power source with quickly changeable output working together with wind turbines.

The best solution in this sense would have been the hydro or pumping power plants with large enough water basin. Unfortunately there are no usable water resources for that in Estonia, so some other, though not so good and more expensive solutions should be found. The main electrical energy producers in Estonia are oil shale electric power plants that are comparatively difficult to regulate and are not suitable to work with wind power plants. To illustrate the wind power-plant output power fluctuations Fig. 1 shows Pakri wind-park one-day (06.02.2006.) load-graph.

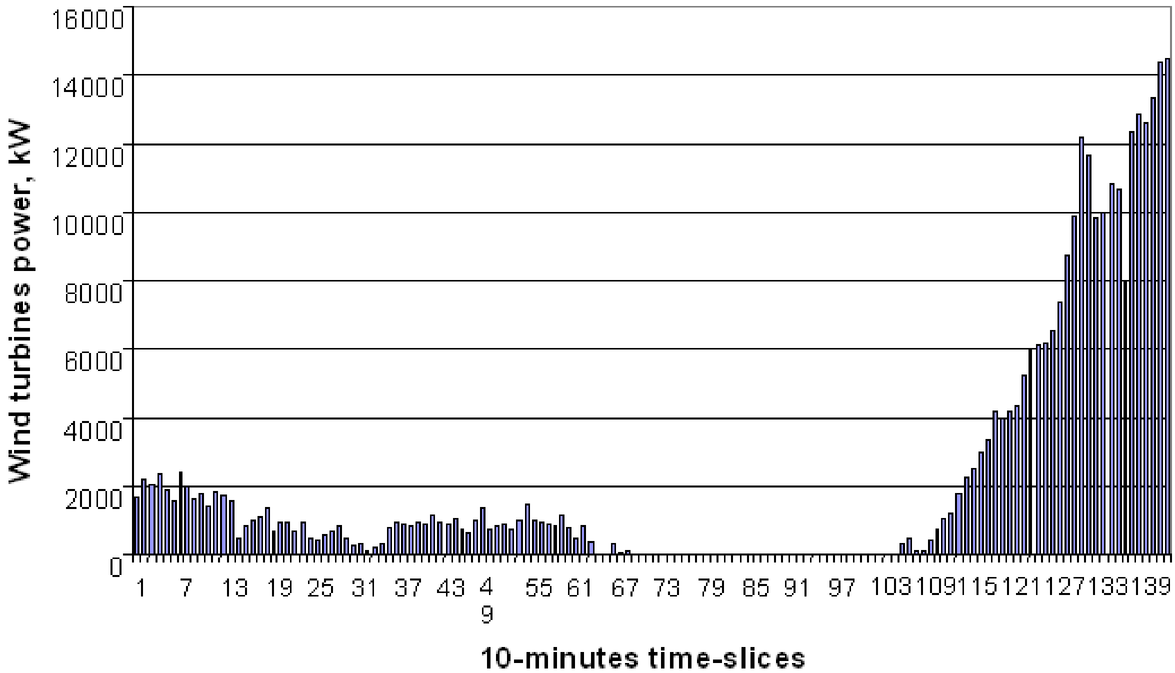

Fig. 1. **Pakri wind-park load-graph at February 2, 2006**

We can see that the output power at the observation day changes from practically zero to 14 000 kW in approximately 5.5 hours, whereas during the output power rise there is 10-minute gap when the output power decrease for nearly 2000 kW.

There is also approximately seven hour period where the wind-park does not produce any energy. The average output power at the first ten hours of the day is less than 1000 kW. So, to guarantee 2/3 of maximum output power for the consumers there should be additional power source of at least 12 000 kW available for 20 hours (approximate energy capacity of 240 000 kW·h). Of course, the wind-park output is mostly more even but the consumers need the power supply also at extreme conditions.

One important exploitation parameter of wind power devices is so called nominal power utilization coefficient η_n - ratio of energy produced during some period to maximal possible energy production by this device at the same period. The maximal production can be found multiplying the nominal power of the device (in our case it is 18 400 kW) by the length of observation period in hours. That can be illustrated by following example.

The energy production of Pakri wind-park on February 6, 2006 was 51 140 kW·h,

$$\eta_n = \frac{51\,140}{24 \times 18\,400} = 0.116 \tag{1}$$

So, η_n = 11.6 %. Using the same methodology we can find nominal power utilization coefficients for all wind-parks in Estonia in year 2007 on the basis of Table 1. The total nominal power of all wind turbines is P_n = 51.8 MW, their energy production W_a = 91.3 GW·h, the length of the year in hours T_a = 8760. The nominal power utilization coefficient of all wind turbines is

$$\eta_n = \frac{W_a}{T_a P_n} = \frac{95\,700}{8\,760 \times 51.8} = 0.211,\ \eta_n = 21.1\ \% \qquad (2)$$

That is comparatively good result, taking into account all circumstances.

Wind power output prognosis

Before the wind-farm or wind turbine is installed first of all it is necessary to find out the wind conditions in given place. When large wind-parks need very extensive preliminary studies then in case of individual small-power wind turbine installed by private owner it is better to get acquainted with earlier research results (e.g. Estonian Wind Atlas data [1]), but as the wind turbine installation is quite expensive it would be wise to make additional measurements.

It is possible to use the wind speed distribution diagrams or tables composed on the basis of longer measurements for different regions. As an example Fig. 2 shows wind speed distribution chart for Tartu presented in Estonian Wind Atlas.

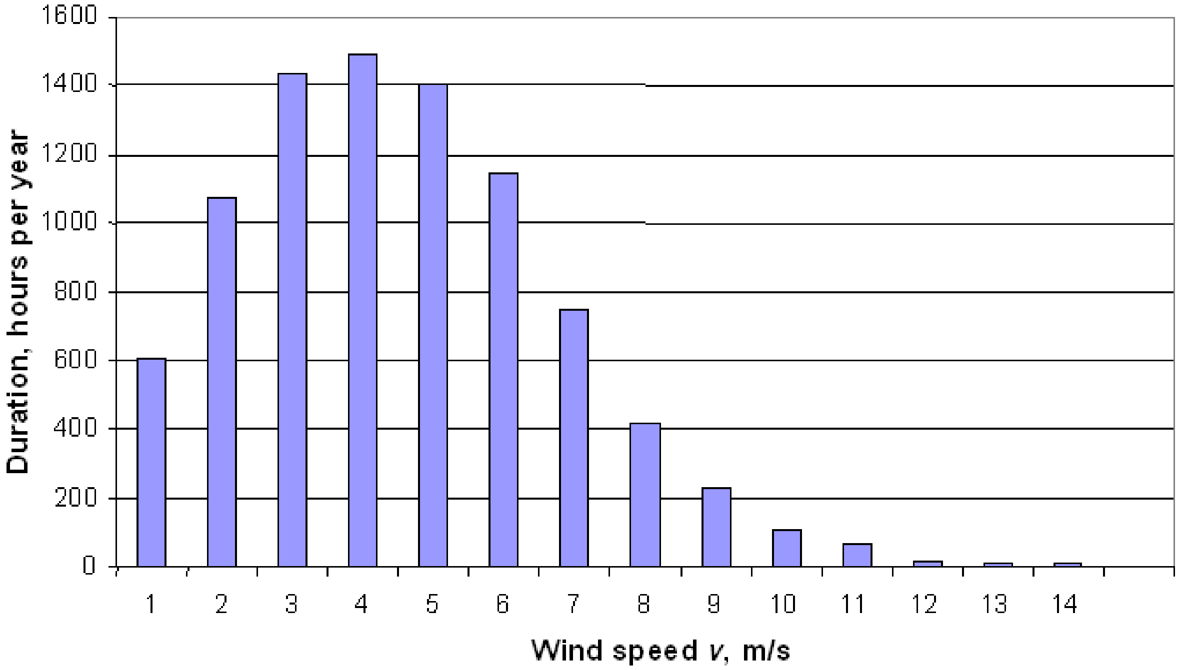

Fig. 2. **Wind speed distribution for Tartu [1]**

If the power curve of the wind turbine is also known, it is possible to find approximate supposed energy production of given wind turbine at given place as:

$$W_v = \sum P_v T_v\ , \qquad (3)$$

where W_v – energy;
v – wind speed;
P_v – the turbine power corresponding to wind speed;
T_v – duration of the wind with the given speed for the observation period (e.g. year).

Let the wind turbine be Nordex 90 [4], as at the Pakri wind-farm. The corresponding power curve is shown on Fig. 3.

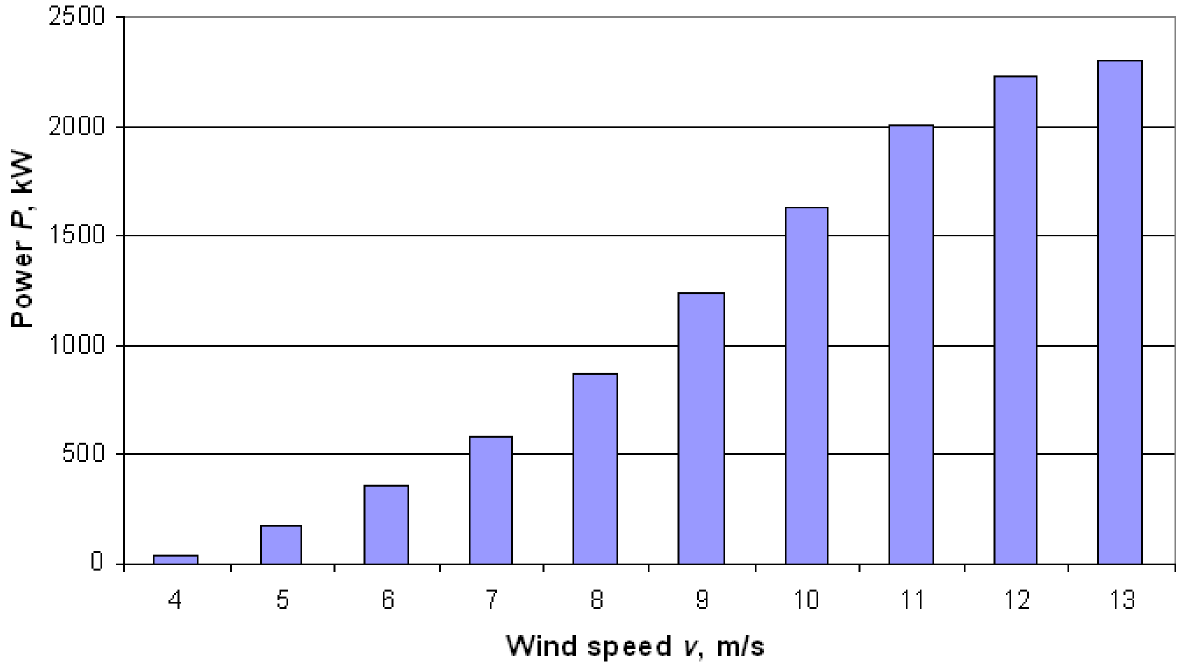

Fig. 3. **Nordex 90 wind turbine power depending on wind speed**

Using Fig. 2 and 3 or rather corresponding numerical data, we can find the approximate energy production of Nordex 90 electrical energy generator per year as 1 261 580 kW·h and the nominal power utilization coefficient per year as 6.3 % if to use the generator in Tartu region.

For 20 kW nominal power wind turbine WP20kW [5] of Tuulinvoima company, the output power dependence on the wind speed of which is shown on Fig. 4, at 90 times smaller output power we get 54 times smaller energy output (23 280 kW·h), but nearly 2 times better nominal power utilization coefficient (13.3 %).

To test the methodology correctness we can use it for working wind turbines, e.g. at Pakri wind-park. Fig. 5 shows the wind speed distribution in Pakri region in July, 2006.

Using this wind speed distribution chart and Nordex90 data from Fig. 2 we get 356 244 kW·h output energy for July that corresponds nearly exactly to the actual average energy output of one generator at given month. The calculated nominal power utilization coefficient is 26.6 % that is just normal for summer months.

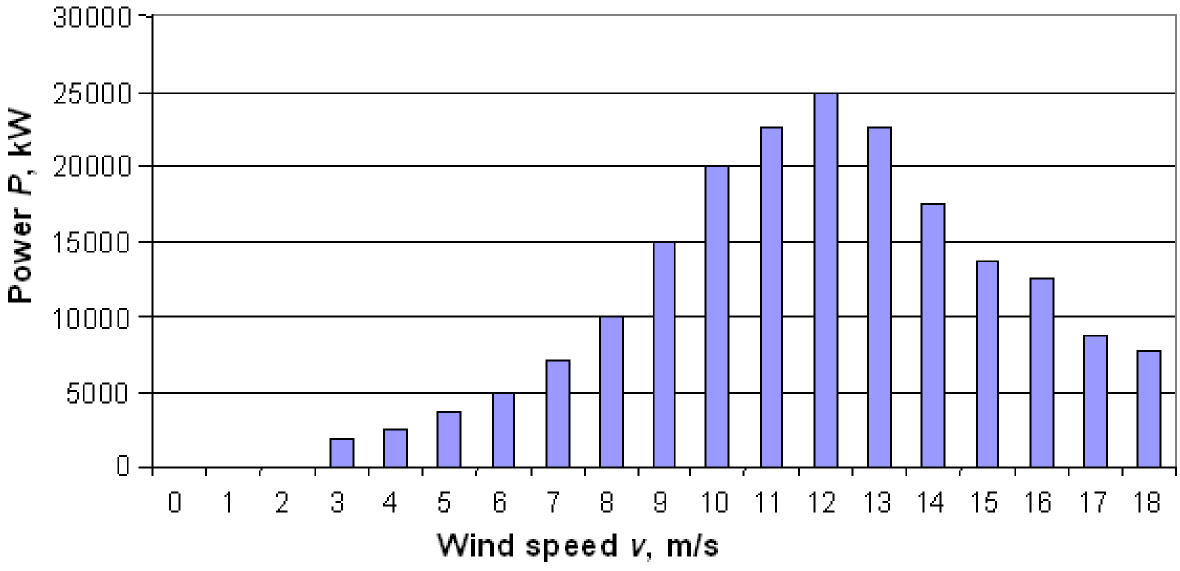

Fig. 4. **Wind turbine WP20kW power output depending on the wind speed**

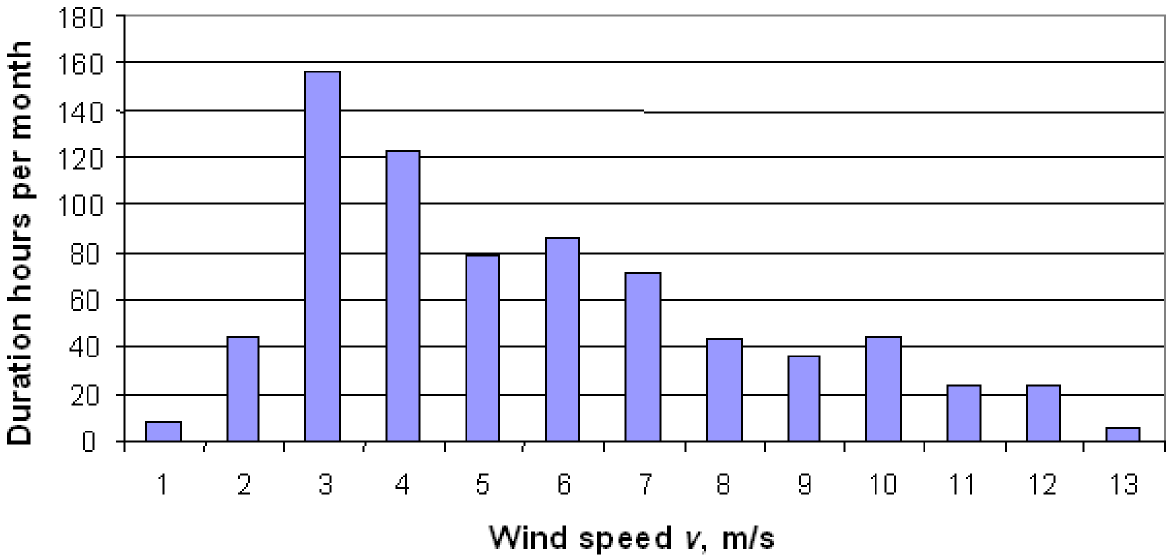

Fig. 5. **Wind speed distribution in Pakri in July, 2006**

Conclusions

The method suggested for determining approximate energy output of the wind turbine before its installation on the basis of wind speed distribution data composed by meteorologists and the power curve of the generator may be useful for choosing the best suitable device by an individual owner.

It is evident that for installation inland more effective are small-power wind turbines that can produce output power at wind speeds less than 3 m/s.

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