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ESTONIAN WIND FARMS' NEED FOR FULL BALANCE POWER

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Estonia had set a target to increase the share of renewable energy sources in the energy production up to 5.1% of total consumption by the end of 2010. There are no large rivers and solar activity is also low in Estonia. Therefore one of the biggest possibilities to achieve that target is to use bio fuels and wind power. Approximately 90% of total electricity is generated from oil shale, hereby oil shale power plants have to cover wind energy deficits. Wind speed is very variable and therefore electric power production by wind turbines varies from zero to nominal power. This is a problem for the power grid.

The current paper analyses whether wind turbines and wind farms need 100% balanced power. Wind data of four weather stations around Estonia were investigated. Wind speeds were calculated to 100 meters above the ground level and Weibull distributions were composed. Distribution and duration of zero energy periods were analysed.

In 2008 zero wind production periods varied from 1 to 7 hours (63 times) and their sum was 137 hours. In these periods wind turbines need 100% balance power.

Introduction

The first larger wind warm in Estonia was Virtsu I. It consists of three Enercon 0.6 MW and one 0.8 MW wind turbine. Three 0.6 MW turbines were installed in 2002 and 0.8 MW turbine in 2008. By 2010 total installed capacity of wind power plants had reached 148.75 MW. The capacity more than 500 MW is in development [1].

If there are some smaller wind turbines and wind farms connected to the electricity system, the system is able to manage with this wind power variations. When the share of wind energy in electricity system grows, the production fluctuation starts to generate more problems to the power

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grid [2]. In Estonia the wind speed varies from zero to 48 m/s (maximum wind speed measured in Ruhnu in 1969) [3]. Larger wind turbines cut in at wind speeds 3–4 m/s and cut out at 25–34 m/s. Wind turbines reach their nominal power at wind speeds 12–14 m/s, larger offshore wind turbines even at 16–17 m/s. The time when all the wind turbines work at their nominal power is short. Therefore wind turbines certainly need some balance power. In Estonia most of the power is produced from oil shale, so oil shale power plants have to handle with wind turbine fluctuating production at the moment. This is quite a problematic task [4] because ramp-up and ramp-down speeds of oil shale power units are slow [5].

In the paper wind turbines balance power demand and situations, when it is needed, are estimated based on presumption that they are located all over Estonia. Analysis of the periods of wind speeds lower than wind turbines' cut-in wind speed (3–4 m/s) is provided.

Wind speed data

In the study the data of four wind measurement stations of Estonian Meteorological and Hydrological Institute (EMHI) was used. Measurement points are located in Narva-Jõesuu, Pakri, Sõrve and Võru, around the perimeter of the Estonian territory (Fig. 1).

Those four measurement points have been chosen because they are covering Estonian border areas. In all four measurement points wind speed was measured at the height of 10 meters above the ground level. All twelve

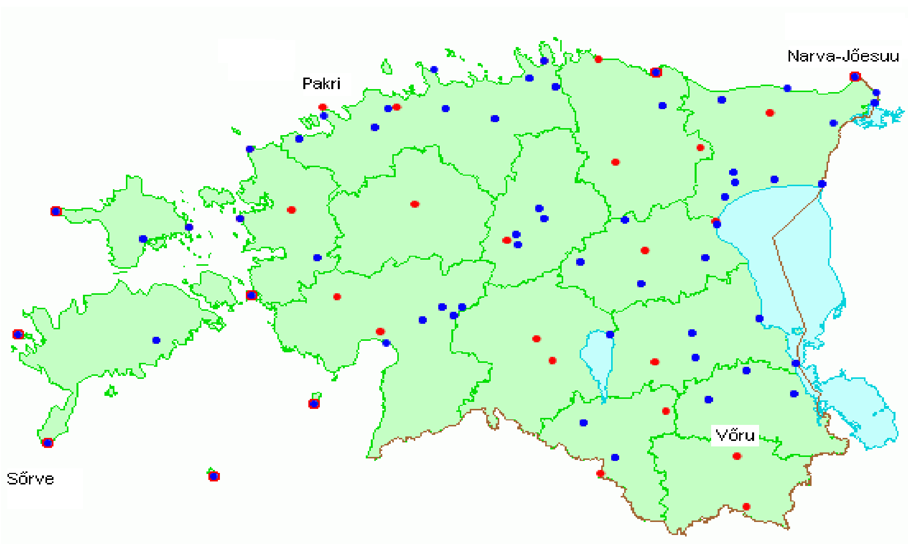

Fig. 1. Location of the four investigated measurement points – Narva-Jõesuu, Pakri, Sõrve and Võru [3].

month wind data of the year 2008 was used in order to cover annual wind speed variations.

10-minute average wind speeds at the height of 10 meters above the ground level in the year 2008 are shown in Fig. 2.

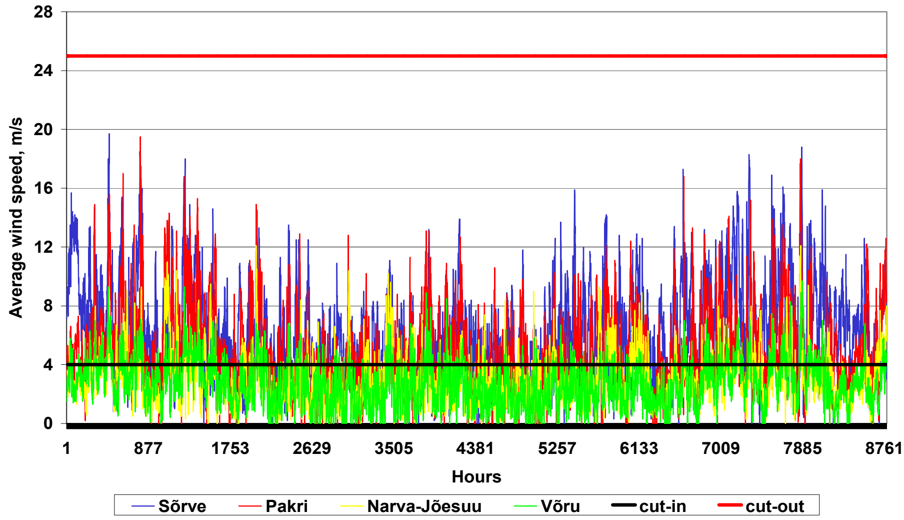

Fig. 2. Average wind speed fluctuations in four measurement points in 2008.

Methodology

Initial wind data from 10 m height of four measurement points was converted to the height of 100 m above the ground level (common hub height of wind turbines). For the data transformation and wind resource estimation WasP 9.0 program was used. All the local obstacles around the measurement points, roughness and contour lines were taken into account.

Local obstacles, roughness and contour lines

Local obstacles around the measurement masts were characterized by their distance from mast, length, width, height and porosity (Fig. 3). All obstacles around the mast are taken into account in order to clean wind data from effects of obstacles to wind flow, because they generate turbulence and therefore recorded wind speed data are influenced.

Porosity of the buildings is zero and for trees it is equal to 0.5. The porosity of trees changes with foliation. Overall porosity of obstacles is shown in Table 1.

The porosity is the ratio between pores (empty area) and total area of a windbreak. To calculate wind climate in the measurement area, map with height contours and roughness lines was created with WAsP Map editor pro-

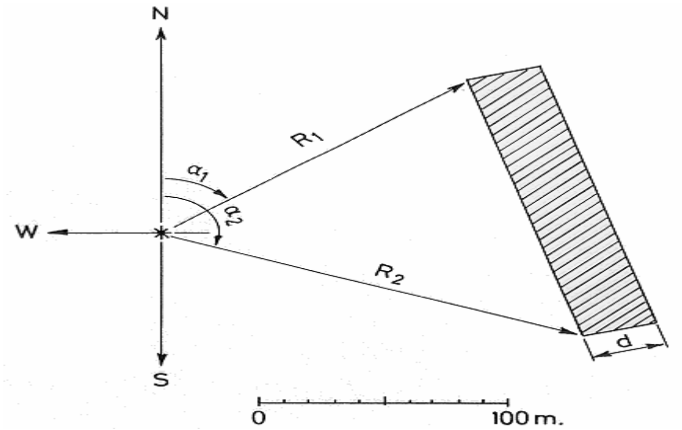

Fig. 3. Scheme of obstacle specification by its position, dimensions and porosity.

α_1 – angle between North vector and the first corner [^{o}], R_1 – radial distance to the first corner [m], α_2 – angle between North vector to the second corner [^{o}], R_2 – radial distance to the second corner [m], h – height of obstacle [m], d – depth of obstacle.

Table 1. **Porosity of obstacles**

Windbreak character	Porosity
Solid (wall)	0
Very dense	< 0.35
Dense	0.35–0.50
Open	> 0.50

gram. The map should cover at least 10–20 km area around the future wind turbine area [6]. Roughness lengths of the investigated sites which were used in WAsP roughness map are shown in Table 2.

Table 2. **Terrain surface and roughness lengths of the investigated sites [7]**

Roughness length Z_0 [m]	Terrain surface characteristics
1.00	City
0.80	Forest
0.50	Suburbs
0.20	Many trees and/or bushes
0.10	Farmland with closed appearance
0.05	Farmland with open appearance
0.008	Mown grass
0.005	Bare soil (smooth)
0.0003	Sand surface (smooth)
0.0001	Water areas (lakes, open sea)

Nordex N90 wind turbine

In the present paper wind turbine production prognoses made are based on characteristics of Nordex N90 turbine and are compared with Pakri Wind Farm's capacity factor. Nordex N90 rotor diameter is 90 m and swept area is 6.362 m^2. Cut-in wind speed is 3 m/s and cut-out wind speed 25 m/s. Rated power is reached at 13 m/s. Nordex N90 nominal power is 2300 kW and calculations are made with 100 meter tubular tower. Nordex N90 wind turbine power curve is given in Fig. 4. Although cut-in wind speed is 3 m/s, the power production rate at wind speeds of 3–4 m/s is very small (1.5–35 kW).

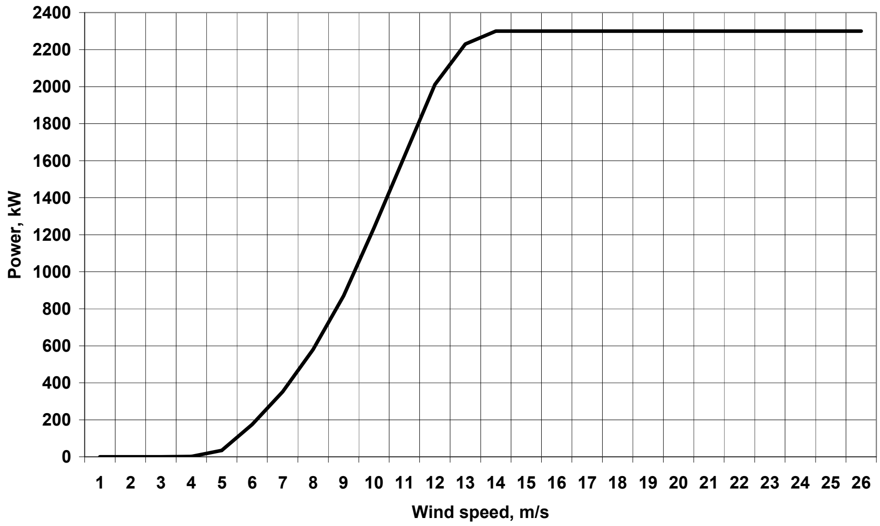

Fig. 4. Nordex N90 / 2300 power curve [8].

One of the largest Estonian wind farms is in Pakri and consists of 8 Nordex N90 wind turbines, where tower height is 80 m. Wind farm covers an area of 46 hectares and total capacity is 18.4 MW. Annual average energy production is 53 GWh. Accordingly, Pakri wind farm capacity factor is 0.329 which is sufficiently good.

Results and discussion

EMHI measurement points at the heights of 10 meters above the ground level are too low to make correct wind climate calculations and wind turbine production prognoses. EMHI wind data is under the influence of local obstacles (trees, houses, etc.).

To make accurate long-term wind turbine production prognoses, measured wind data was calculated to wind turbine hub height, 100 meters above the ground level.

Wind speed variation data in Narva-Jõesuu, Pakri, Sõrve and Võru at 100 meters height is shown in Fig. 5.

From Fig. 5 it follows that wind speed is higher than cut-in speed most of the time in coastal areas and islands like Pakri and Sõrve. But there are also several occasions when wind speed at the height of 100 meters above the ground level is below 4 m/s at all observed sites. During these periods all installed 150 MW of wind power was not producing electrical energy.

Average wind speed differs greatly at site locations. In inland at the height of 10 meters above the ground level, annual average wind speed is only 2.5–3m/s. In coastal areas the situation is much better and there wind speeds are 5–6 m/s [9].

Difference in the wind speeds at 10 m and 100 m heights is about 2–3 m/s. At inland of Võru site it is 5.19 m/s, but in Sõrve (Saaremaa Island) it is 8.06 m/s (Fig. 6). But even in locations with good wind conditions there are periods, when wind speed is lower than wind turbine cut-in level.

Wind speed Weibull distributions for all four measurement points are shown in Fig. 6.

An important parameter is length of the continuous period, when wind turbines are not working. Those zero energy production periods are largely depending on wind farm location. The percentage of time of wind speeds below 4 m/s is 37.7 at inland (Võru) and 18.5 in island of Saaremaa (Sõrve). Although it differs largely according to wind turbine location, there are no onshore locations in Estonia, where wind turbines are producing all the time.

Another relevant indicator is wind turbine zero energy production period durability – frequency distribution of the periods with certain duration (Fig. 7).

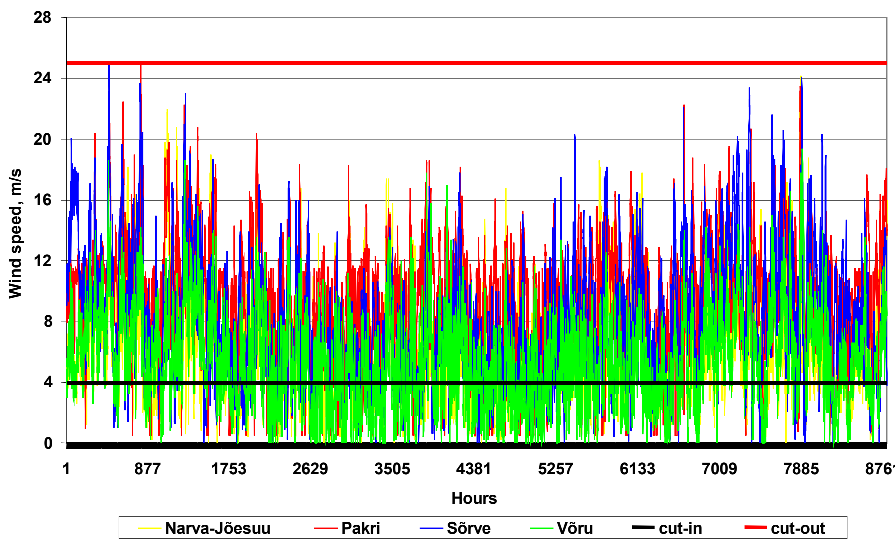

Fig. 5. Wind speed in 4 measurement points at the height of 100 meters above the ground level.

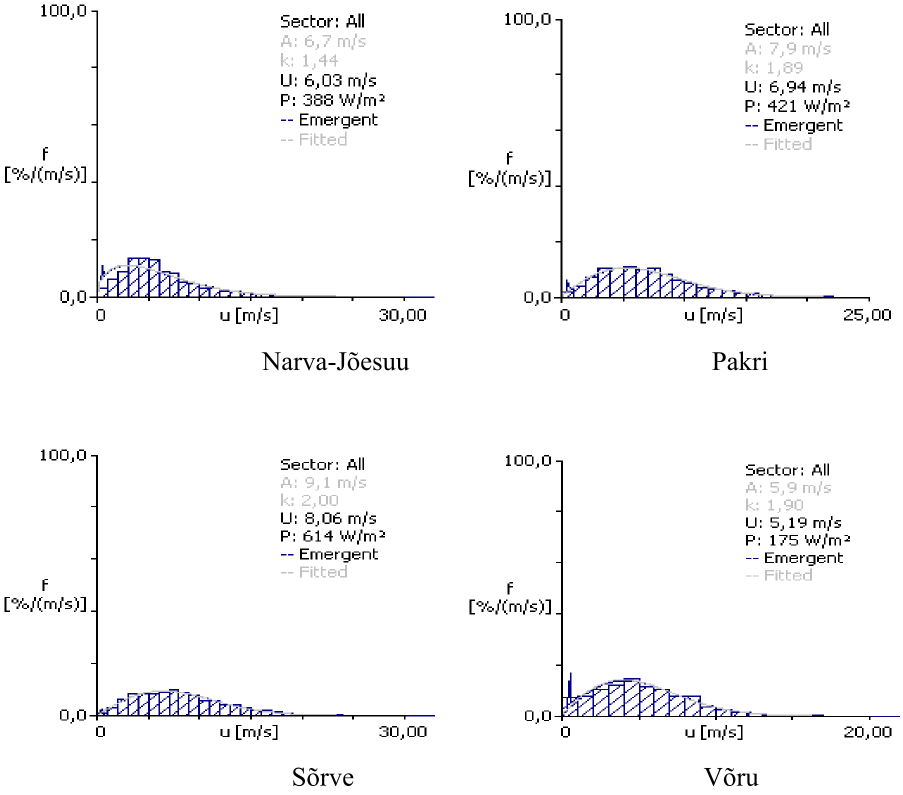

Fig. 6. Narva-Jõesuu, Pakri, Sõrve and Võru wind speed Weibull distributions at the height of 100 m.

A – Weibull parameter *A* [m/s], k – Weibull parameter *k* (shape factor), U – average wind speed [m/s], P – power density [W/m^2].

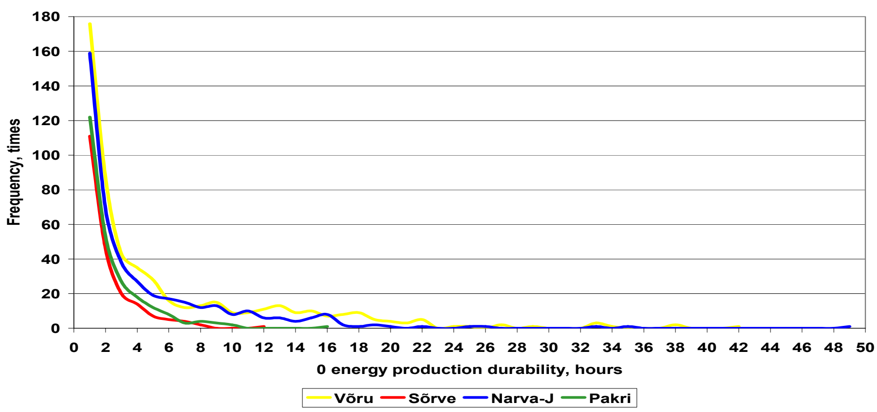

Fig. 7. Zero energy production durability in Võru, Sõrve, Narva-Jõesuu and Pakri in 2008.

Number of zero energy production periods and their durability depends on wind turbine location. The number of one hour lasting production gaps was 176 in Võru and 111 in Sõrve. Total number of production gaps in Võru was 539 and in Sõrve 211. Most of the zero energy production periods last up to 6 hours (70–95% of all production gaps, depending on location). The longest 0-energy production period was in Narva, where wind speed was continuously below wind turbine cut-in wind speed for 49 hours. In Sõrve the longest continuous 0-energy production period was 16 hours. The longest wind turbine production gaps are usually in summer and in winter.

In Fig. 8 occasions, when wind speed was lower than 4 m/s and wind turbines were not producing electricity in all over Estonia in 2008 are shown.

In the year 2008 there were 63 occasions of zero energy production cases in total all over Estonia. 46% of all occasions where with durability up to one hour. The biggest overall wind energy production gap in 2008 was 7 hours. Total annual Estonian zero wind power production periods in year 2008 was 137 hours (1.6%).

Results of annual energy production prognoses and capacity factors with Nordex N90 wind turbine of four measurement sites are shown in Table 3.

Wind turbine capacity factor differs depending on wind turbine location. In inland (Võru) usage coefficient is mostly less than 0.2, but in coastal areas and in islands it could be over 0.4.

Annual energy production of Pakri Nordex N90 calculated from EMHI wind data was 6844 MWh and usage coefficient 0.34. In the same year real average energy production of Pakri Wind Farm one wind turbine was 6625 MWh and usage coefficient 0.329. Pakri Wind Farm one turbine production and usage coefficient are lower, because there the turbines height is 80 m.

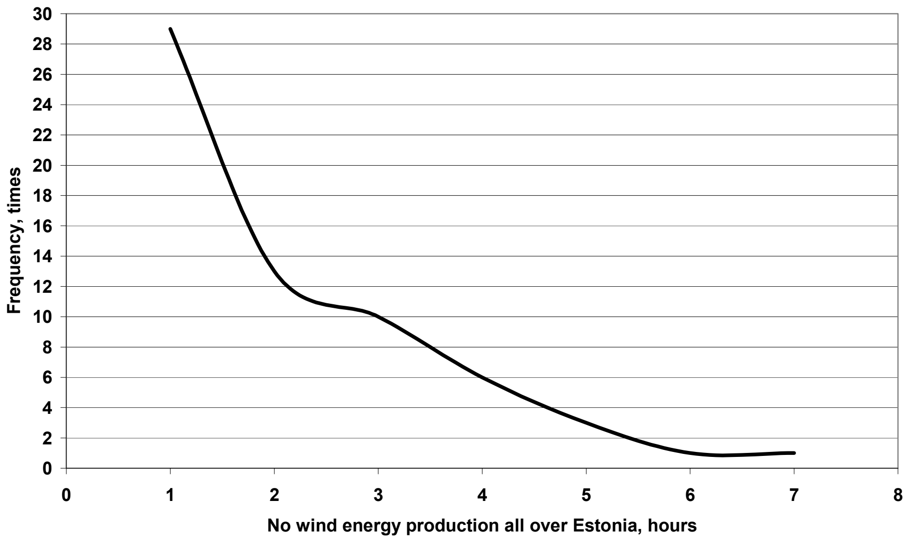

Fig. 8. Distribution of zero energy periods in all over Estonia in 2008 – wind speed is lower than wind turbine cut-in level (4 m/s).

Table. 3. **Nordex N90 (2.3 MW, hub height 100 m) annual production prognoses in Narva-Jõesuu, Pakri, Sõrve and Virtsu**

Location	Wind speed, m/s	Power density, W/m^2	NET AEP, MWh	Capacity factor
Narva-Jõesuu	6.0	388	5412	0.27
Pakri	6.9	421	6844	0.34
Sõrve	8.1	614	8306	0.41
Võru	5.2	175	3711	0.18

Wind is an extremely fluctuating energy source. In 2008 in all four measurement sites minimum wind speed at the height of 10 meters above the ground level was 0 m/s, maximum wind speed was 19.7 m/s. Wind speed range is even higher at wind turbine hub heights (100 meters above the ground level). In cases of storm it would end up with wind turbine cut-out at wind speeds 25 m/s and higher.

Electricity production of wind turbine and wind park can vary from 0 MW to maximum output, and at wind speeds higher than 25 m/s drop from maximum output to 0. This is the worst case for wind turbine production balancing and needs fast ramp-up peak power plants. Estonian oil shale power plants cannot balance big production falls.

Even in Sõrve, the place with almost best onshore wind conditions in Estonia, there are times when wind speed drops below cut-in wind speed. It is positive that in 2008 there were no occasions, when wind speed was higher than 25 m/s, and that means there were no wind turbine cut-outs from maximum power.

With the increase in turbine tower height and changes in rotor diameter dimension it is possible to reduce the amount and length of wind turbine zero production periods, but not to avoid them. Currently, when Estonian total installed wind energy has reached 150 MW, peak power plants (e.g. peak power hydro pump or gas turbine station) for the fast wind power lack compensation are needed. Another problem with wind energy is low reliability of long-term wind speed forecasting.

Conclusions

- In the year 2008 one-hour average wind speed at wind turbine hub height (100 m above the ground level) changed from zero to 25 m/s. That means there were no wind turbine cut-outs from the maximum power limit.
- Wind speeds with range below 4 m/s covered 18.5% of the year, and about 95% of all production gaps were shorter than six hours.
- In 2008 totally 137 hours were counted (63 occasions with durability from 1 to 7 hours), when wind speed in all over Estonia was lower than wind turbine cut-in wind speed (4 m/s).

- During these zero periods wind farms need 100% of balance power, but the periods are not longer than 6–7 hours and could be covered with some peak power plant (e g. hydro pump station).
- Compensation of wind farms' fluctuating production is a very complicated task for oil shale power plants and needs additional investigations. Wind speed changes are difficult to forecast, plants cannot change their power production as quickly as wind speed changes, and their minimal load is also limited.

REFERENCES

1. Web page of Estonian Wind Power Association. Available from: http://www.tuuleenergia.ee/about/statistika/.
2. *Agabus, H., Tammoja, H.* Estimation of wind power production through short-term forecast // Oil Shale. 2009. Vol. 26, No. 3S. P. 208–219.
3. Web page of Estonian Meteorological and Hydrological Institute. Available from: http://www.emhi.ee/index.php?ide=6,747,750.
4. *Palu, I., Oidram, R., Keel, M., Tammoja, H.* Balancing of wind energy using oil-shale based power plants at erroneous wind forecast conditions // Oil Shale. 2009. Vol. 26, No. 3S. P. 189–199.
5. *Keel, M., Kilk, K., Valdma, M.* Analysis of power demand and wind power changes in power systems // Oil Shale. 2009. Vol. 26, No. 3S. P. 228–242.
6. WAsP 9.0 Help Facility and On-line Documentation. Available from: http://www.wasp.dk/support/FAQ/WebHelp/Wasp9.htm.
7. *Pertmann, I.* Wind measurement procedures and data series processing by WAsP application software. – Tallinn: Tallinn University of Technology, 2002. 74 pp.
8. German Wind Energy Association. Wind Energy Market 2007/2008. - Berlin, Germany, 2008. 130 pp.
9. *Kull, A.* Estonian Wind Atlas. – University of Tartu, Faculty of Biology and Geography, Institute of Geography. Tartu, 1996 [in Estonian].

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