Proc. Estonian Acad. Sci. Eng., 2000, **6**, 1, 61–69
https://doi.org/10.3176/eng.2000.1.05

WIND DYNAMICS IN THE MOONSUND ARCHIPELAGO

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Received 11 December 1998, in revised form 15 March 1999

Abstract. Wind speed dynamics measured during one year with an automatic wind station installed on the Harilaid Islet is analysed from the point of view of the wind energy utilization. Special attention is paid to the dynamic behaviour of wind in the speed range of 8–12 ms^{-1}. It is shown that increasing of the hub height over the standard (30–40 m) adds to the annual energy yield about 1% per every added meter.

Key words: wind speed dynamics, wind energy utilization.

1. INTRODUCTION

Wind speeds in Estonia have been investigated for a long time and the results have been generalized in [1–3]. Unfortunately, all these investigations are related with the wind statics (assessment of the average speed, capacity and direction during a long interval – month, season, year, etc.). Due to the reasons explained in [4], the wind speed dynamics is important in view of wind energy utilization when wind electricity generators operate connected to the common power grid [5,6]. The dynamic behaviour of the wind can be assessed only by continuous measurements and therefore measurements must be automatically controlled that was not possible until recently.

In the present article, the data measured in the WICOM-C automatic wind station installed on the Harilaid Islet (23°2.7′ E, 58°56.4′ N) is analysed. Measurements have been made every 10th second, but the data have been stored in the database averaged for 10 min intervals, what is much more frequent than the 3 h intervals used in the earlier hydrometeorological observations [3] and thus for the first time in Estonia they give information about the wind dynamics. Actually, automatic measurements with the same time interval have been made earlier at Kootsaare (the island of Hiiumaa) and on the Vormsi, Osmussaare, and

Prangli islands [1], but the results of wind measurements have not been published and wind dynamics has not been analysed. A peculiarity of the measurements on Harilaid is also that for the first time an annual database from the autumn equinox of 1997 till the same day in 1998 has been compiled. The background of the present analysis is related to the implementation of wind as a power source and therefore consideration of wind direction is not significant, but the process dynamics in a certain range of instantaneous speeds v and wind speed behaviour at different heights H are of interest. Wind measurements on Harilaid have been made at three different heights: 20, 35, and 50 m [7].

2. CHARACTERISTIC FEATURES OF A WIND POWER GENERATOR

The capacity of a wind power generator in the range of $v_{\text{min}} < v < v_{\text{stab}}$ is $P = f(v^3)$. The capacity at the wind speed below the minimum value v_{min} and above its limit value v_{lim}, endangering the wind generator, is zero. For the safety of the equipment, the wind turbine is stopped at $v > v_{\text{lim}}$. In the range of stabilization, $v_{\text{stab}} < v < v_{\text{lim}}$, the capacity (for an ideal regulator) is equal to the installed nominal value $P_{\text{nom}} = \text{const}$. The minimum speed by starting a wind generator is in the present work taken as 4 ms^{-1} and $v_{\text{stab}} = 12$ ms^{-1}. The curve of the utilized relative capacity $P^* = P(v)/P_{\text{nom}}$ is given in Fig. 1.

It is evident that wind velocities $v < 8$ ms^{-1} are not of interest since the obtained capacity and the generated amount of energy are very low. In the Moonsund Archipelago maximum measured wind speed is 25 ms^{-1}. The wind speed in the range of $12 < v < 25$ ms^{-1} increases significantly the potential wind energy reserve, but not the real capacity which is limited by respective regulation. Only bigger wind turbines of certain companies (e.g., Zond Z-40) have been designed for wind speeds up to 40 ms^{-1}. In our work we have focused

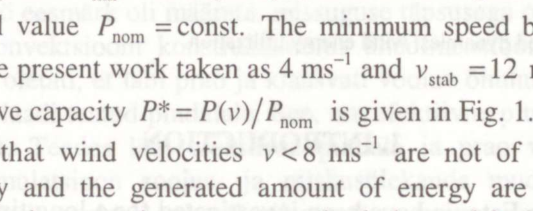

Fig. 1. Relative capacity of a wind generator P^* as a function of the average wind speed v.

on the wind speeds in the range of $8 < v < 12$ ms^{-1} since there a change in the wind speed for 30% may result in the 90% variation of the capacity of a wind power generator.

3. THE AVERAGED PARAMETERS OF THE WINDS ON HARILAID

In Table 1 the annual average values on three heights for the medium (v_{med}), maximum ($v_{\max}$), minimum ($v_{\min}$), and absolute maximum $[\max(v_{\max})]$, wind speed are shown. In the given year the absolute minimum speed is zero at all three heights. Dependence of the average medium wind speed on the height is approximately described as $v_2 = v_1 (H_2/H_1)^{0.15}$ [8] where v_1 and v_2 are average speed values at the heights H_1 and H_2, respectively.

Table 1. Wind characteristics on Harilaid from 1997 Sept 21 to 1998 Sept 21

Wind characteristic	Height, m		
	20	35	50
v_{med}	7.11	7.55	7.98
$v_{\max}$	12.73	13.32	13.82
$v_{\min}$	2.58	2.79	3.08
$\max(v_{\max})$ 1998 Feb 28	26.0	28.1	29.6
Annual normalized energy E^*	0.85	1	1.15
Wind energy efficiency η_{E}	0.31	0.26	0.22
Relative yield W^*	0.23	0.27	0.31

In Table 1 the "real" annual normalized energy E^* (normalized to the energy at the hub height 35 m) is defined as

$$E^* = \sum_{h=1}^{h=52560} P^*(h, H) \Big/ \sum_{h=1}^{h=52560} P^*(h, 35), \tag{1}$$

where h is the number of the 10 minute interval and the relative capacity is

$$P^* = P_{\text{nom}} (v(h) - v_{\min})^3 / (v_{\text{stab}} - v_{\min})^3 . \tag{2}$$

The weak dependence of E^* on the hub height in the case of regulation in the limits $v_{\text{stab}} < v(h) < v_{\text{lim}}$ puts up a question whether it is reasonable in the offshore conditions to build a wind turbine higher than it is required for providing the safe rotation of blades.

The wind energy efficiency η_{E} is the ratio of energy yield with capacity regulation to the corresponding energy yield without it (the natural wind energy resource)

$$\eta_{\mathrm{E}} = \frac{\sum_{h=1}^{h=52650} P_{\mathrm{nom}} (v^*(h) - v_{\min})^3 / (v_{\mathrm{stab}} - v_{\min})^3}{\sum_{h=1}^{h=52650} P_{\mathrm{nom}} (v(h) - v_{\min})^3 / (v_{\mathrm{stab}} - v_{\min})^3}, \tag{3}$$

where

$$v^*(h) = v(h) \text{ if } v(h) \le v_{\mathrm{stab}},$$

$$v^*(h) = v_{\mathrm{stab}} \text{ if } v(h) > v_{\mathrm{stab}}.$$

Here η_{E} has a low value ($\eta_{\mathrm{E}} << 1$). It shows that operating directly with the meteorological database is not correct.

Another item of interest is the relative yield W^*, which is the ratio of the annual normalized energy to the amount of energy which could be generated in the wind power plant by its operation at the nominal load

$$W^* = E^* \Big/ \sum_{h=1}^{h=52560} P_{\mathrm{nom}}. \tag{4}$$

Table 1 as well as the wind rose (Fig. 2) show static data. We can see that the highest relative capacity is obtained with the SW winds and the lowest with the

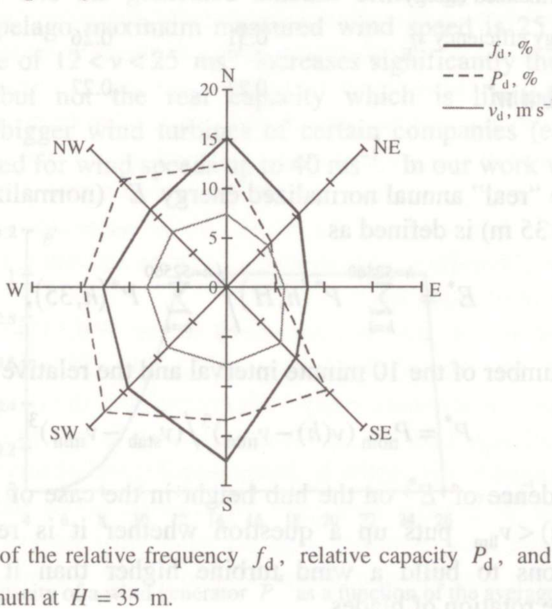

Fig. 2. Dependence of the relative frequency f_{d}, relative capacity P_{d}, and average wind speed v_{d} on the wind azimuth at $H = 35$ m.

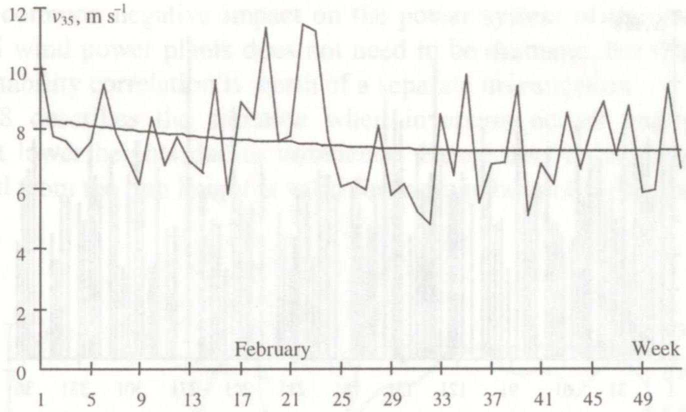

Fig. 3. Weekly average wind speed v_{35} on Harilaid Islet at $H = 35$ m.

E winds. Dynamics of the average wind speeds during the year is shown in Fig. 3. The wind speed of the considered year with the local maximum in February is evidently not typical for Estonia since it is known that the highest winds in Tallinn prevail in November, December, and January [9].

4. DYNAMIC WIND PARAMETERS ON HARILAID

Further we shall consider wind parameters independent from its direction. The wind speed contains a periodic and a random component. The periodic change is given in Fig. 4 where the vertical lines show the amplitude of the daily average wind speed on "windy" days, which have a local maximum relative to the preceding and following days, at the height of 35 m. Thus the growing and decreasing trend of the average wind speed are both screened out. Table 2 shows frequency of the number of days during which the wind speed was either growing or declining. Periods seen in Fig. 4 are irregular and so are the values of the average speed.

Table 2. Frequency of the periods with the monotonous change of the wind speed

Period in days	2	3	4	5	6
Frequency of occurrence	27	29	23	13	5

Figure 5 shows the number of days when at least once a day within one hour the generated capacity varies for a certain amount. The number of cases when the capacity varies for the shown amount is actually bigger since for variable

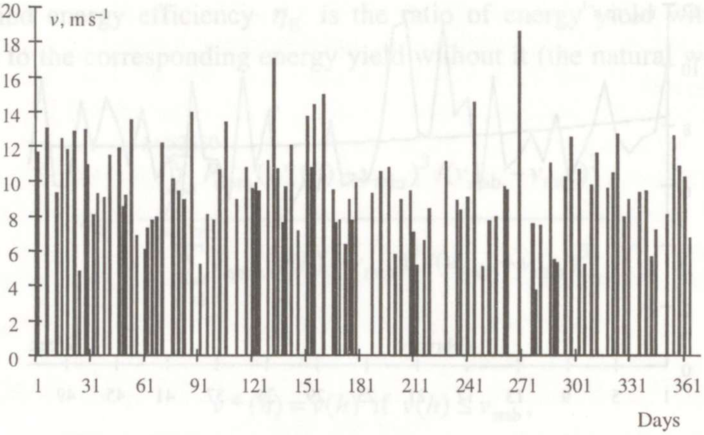

Fig. 4. "Windy" days from 1997 Sept to 1998 Sept.

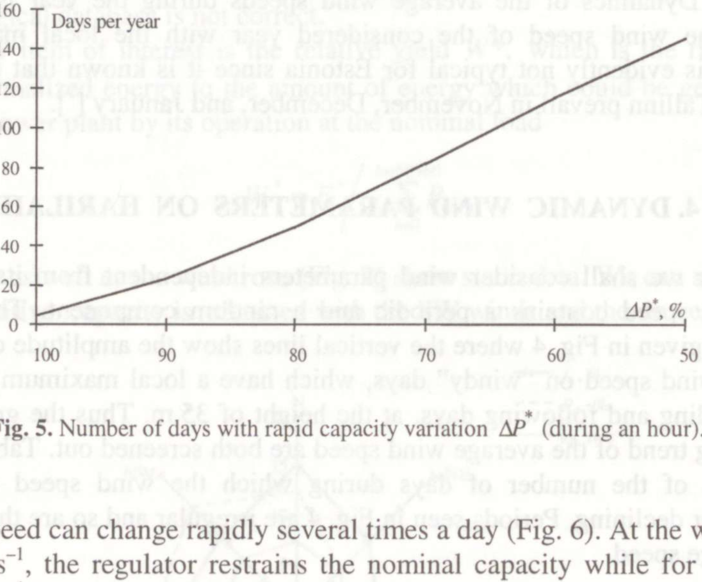

Fig. 5. Number of days with rapid capacity variation ΔP^* (during an hour).

wind its speed can change rapidly several times a day (Fig. 6). At the wind speed over 12 ms^{-1}, the regulator restrains the nominal capacity while for the speed below 4 ms^{-1} it is zero.

In Fig. 7 the wind speeds measured on Harilaid Islet and at the Tahkuna wind power plant (22°31′ E, 59°04′ N) at the same height for three days are shown. The first two days (June 15th and 16th) were characterized by changing winds while the wind on the last day was rather stable (the day with the highest energy yield in the whole year).

Despite the highly changeable winds on Harilaid, in the critical range of speeds, during the first two days rapid change of the wind speed on Harilaid and Tahkuna never coincided. Examples of the timely shift of the wind speeds in geographically separated monitoring sites can also be found in the literature [10].

Thus, the common negative impact on the power system of the geographically distributed wind power plants does not need to be dramatic, but the problem of power unstability correlation is worth of a separate investigation.

Figure 8 describes the situation when inversion occurs and the wind is stronger at lower heights due to turbulence. Hence the "linear" dependence of wind speed from the hub height is valid for average but not for the instantaneous values.

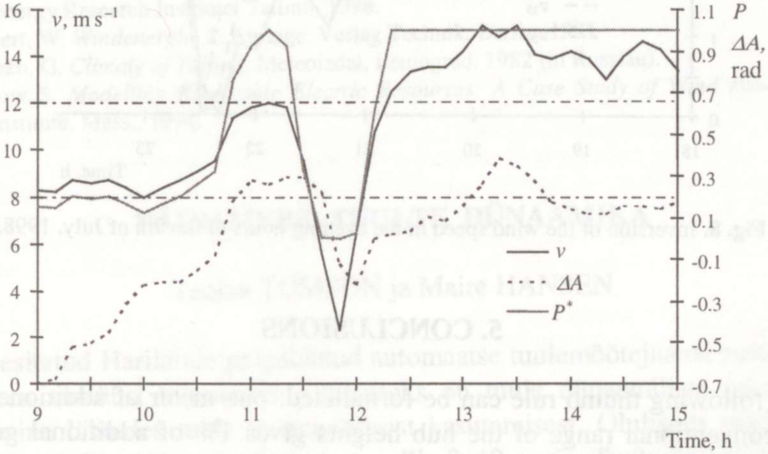

Fig. 6. Variation of the wind speed v, deviation of the wind azimuth ΔA from the average azimuth 160 deg, and relative capacity P^* from 0900 to 1500 h on a typical day.

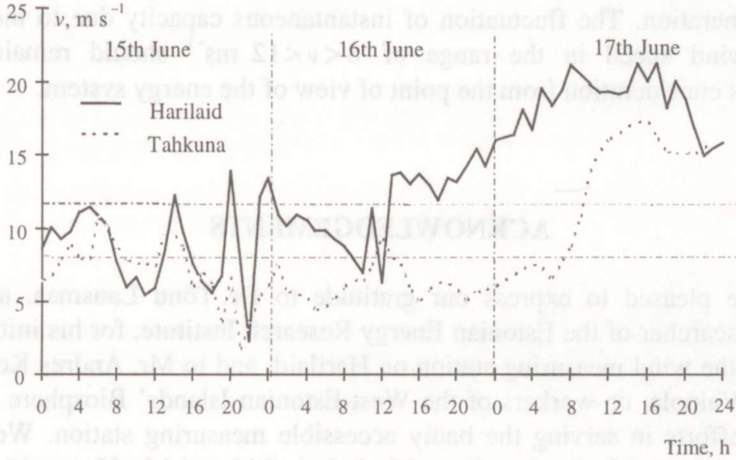

Fig. 7. Comparison of wind speeds on the Harilaid Islet and Tahkuna Peninsula in June 1998.

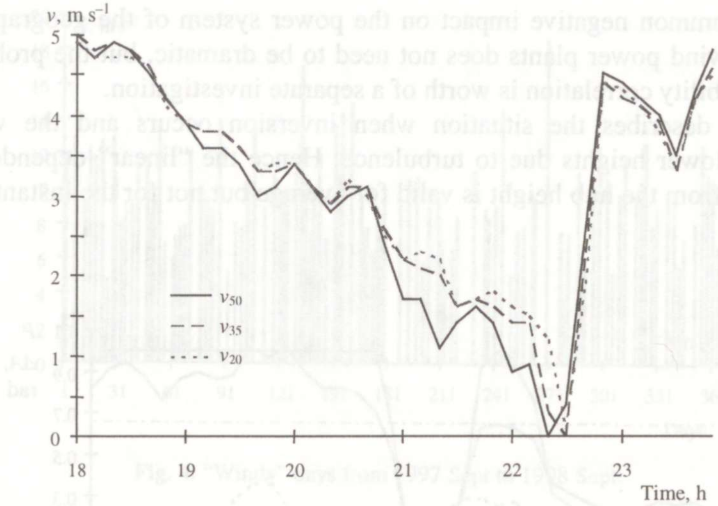

Fig. 8. Inversion of the wind speed in the evening hours of the 9th of July, 1998.

5. CONCLUSIONS

The following thumb rule can be formulated: one meter of additional height in the conventional range of the hub heights gives 1% of additional generated energy yield for a wind power station in offshore conditions. In the West-Estonian Archipelago the SW winds carry the highest energy. Their energy reserve is 2–3 times higher than that of the E or NE winds. Therefore the Estonian western coastal area, which is mostly covered with forest at the east side, the conditions should be most suitable for the development of wind based energy generation. The fluctuation of instantaneous capacity due to the highly varying wind speed in the range of $8 < v < 12$ ms^{-1} should remain under scrupulous consideration from the point of view of the energy system.

ACKNOWLEDGEMENTS

We are pleased to express our gratitude to Dr. Tõnu Lausmaa, a former Senior Researcher of the Estonian Energy Research Institute, for his initiative in installing the wind measuring station on Harilaid, and to Mr. Andres Kortel and Mr. Teet Vainola, co-workers of the West-Estonian Islands' Biosphere Reserve for their efforts in serving the badly accessible measuring station. We should also like to thank Mr. Ruuben Post, Mr. Indrek Sild and Mr. Urmas Jõeleht for decoding the data of the Tahkuna wind power plant and providing the authors with the material for comparison.

REFERENCES

1. Kärsna, A. *Tuule-energia jaotusest Eestis.* Eesti Loodusvarade Instituut, Tallinn, 1940.
2. *Eesti NSV kliimaatlas.* Tallinn, 1969.
3. Kull, A. *Eesti tuuleatlas.* Dissertatsioon. Tartu Riiklik Ülikool, Tartu, 1996.
4. Oidram, R. Kas tuuleenergia tootmine Eestis on mõistlik? *Tehnika ja Tootmine*, 1991, 7/8, 30–32, 9/10, 25–28.
5. Tarand, A. Energeetika teed ja eksiteed. *Eesti Loodus*, 1992, 4, 197–201.
6. Tiit, V. and Mättas, L. Tuuleenergia kasutamisvõimalustest Eestis. *Eesti Põllumajandusülikooli Teadustööde Kogumik*, Tartu, 1996, 189, 138–146.
7. Lausmaa, T. *About Estonian Wind Energy Resource. Research project 1994–1996.* Estonian Energy Research Institute, Tallinn, 1998.
8. Bennert, W. *Windenergie.* 2. Auflage. Verlag Technik, Berlin, 1991.
9. Prilipko, G. *Climate of Tallinn.* Meteoizdat, Leningrad, 1982 (in Russian).
10. Bernow, S. *Modelling Renewable Electric Resources: A Case Study of Wind Power.* Tellus Institute, Mass., 1994.

VÄINAMERE TUULTE DÜNAAMIKA

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On esitatud Harilaiule paigaldatud automaatse tuulemõõtejaama aastapikkuse andmerea analüüsi tulemused. Uudsuseks on tuule dünaamiliste parameetrite käsitlemine lähtudes tuule energeetilisest kasutamisest. Oluliseks tuleb pidada tuule dünaamilist käitumist kiirusintervallis 8–12 m s^{-1}. Tuulejõujaama kõrguse suurendamine üle standardkõrguse (30–40 m) annab iga meetri kohta elektri aastatoodangus võitu 1%.