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PERFORMANCE OF DISSIPATED WIND TURBINES

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Abstract. Strong dependence of the generated wind power on the wind speed makes the incorporation of large scale wind energy into Estonian power supply system difficult. In the paper it is shown that distribution of the wind turbines over a wider geographic area may solve this problem.

Key words: wind dynamics, wind energy, dissipation of wind turbines.

1. INTRODUCTION

If Estonia is to meet the targets of the Kyoto Protocol, renewable energy is to be used more extensively. The Estonian wind energy resource, estimated as 2800 GWh [1], will undoubtedly be developed first. To start wind energy utilization, the resource and restrictions to its use must be studied thoroughly. Wind speed monitoring at the height of 10–12 m has been carried out in Estonia for many years. During this time, long-term statistics of three hour average values have been well documented [2–4] and the wind statics is relatively well known. Due to the peculiarities of the Estonian power system, discussed below, the wind dynamics is also of significant importance. Up to now only a single paper [5] has been devoted to the wind dynamics on the western coast of Estonia where most of the wind resource is concentrated.

The objective of the present paper is to expand the wind dynamics database simultaneously to several locations and to show how dissipation of wind turbines allows to reduce the problems caused to the power system by wind dynamics. It is known [6] that in distant sites wind speeds and their variations do not coincide and global influence of dissipated wind turbines on the power system is always less than that of a concentrated wind farm. The influence of dissipated turbines on the German power system was analysed in [7] with the time intervals Δ_h equal to 1, 4, and 12 h. We shall use databases with the 0.5 h time step, but the wind power increments will be calculated for 1 and 4 h time intervals Δ_1 and Δ_4 too.

2. PECULIARITIES OF THE ESTONIAN POWER SYSTEM

Practical use of renewable energy resources is still in its infancy in Estonia. That is partly caused by the character of the Estonian energy system. Predominant fuel in Estonia is an indigenous fossil fuel *oil shale*, which forms a basis for the Estonian energy sector. Although oil shale has low calorific value, it can be produced rather inexpensively in open cast mines. It is used as a fuel in thermal power plants, including some CHP plants. The conventional load factor of big boilers (100 and 200 MW) is high. A generating plant of this type cannot follow rapid changes in wind turbine power output. The hydropower resource in Estonia is practically insignificant and therefore variable power output of wind turbines must be balanced with the running reserve of oil shale power plants. This in turn makes boilers to operate in a badly polluting transient regime and therefore there is a danger that development of wind energy under such conditions will work against the Kyoto Protocol [8].

3. WIND POWER INCREMENT

A single conventional wind turbine creates high relative power increments ΔP^* which have been investigated for the wind speed range of $8 < v < 12$ m s^{-1} for Harilaid islet (HRL, Fig. 1) [5].

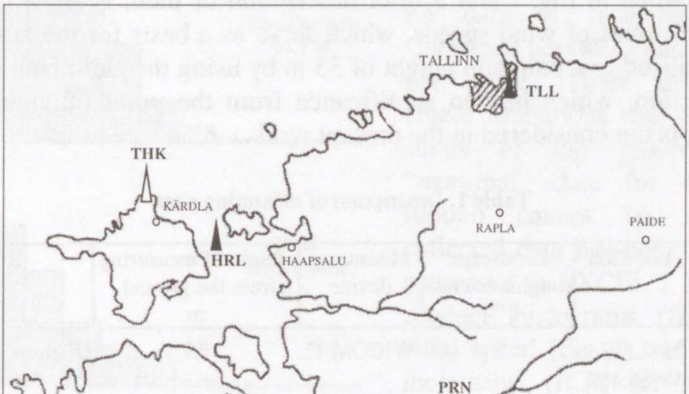

Fig. 1. Locations of synchronous wind monitoring sites in West Estonia.

The relative power increment ΔP^* at instant h can be determined as

$$\Delta P_j^*(h) = P_j^*(h + \Delta_h/2) - P_j^*(h - \Delta_h/2),$$

where P_j^* is the relative power of the jth wind turbine in a group of turbines.

The power increment suppression factor for a group of n wind turbines can be determined as

$$k_\Delta = \Delta P_\Sigma^*(h) \big/ \max\{\Delta P_j^*(h)\}, \tag{1}$$

where the power increment of the whole group ΔP_Σ^* and that of a single jth turbine ΔP_j^* are given in relative units. We estimate the power increment suppression factor using the maximum increment of any single turbine.

4. SYNCHRONOUS WIND DATABASE

Wind speed measurements with an interval of 0.5 h were made at the Tallinn (TLL), Pärnu (PRN) and Kuressaare (KRS) airports, which in addition to the HRL give information about the wind dynamics in Estonia.

Due to the specifics of aviation, measurements were made in the 20th and 50th minutes of each hour using UTC. The sites at which the measurements took place are shown in Fig. 1 and a brief description of them is shown in Table 1. The instant values of wind speeds, which serve as a basis for the analysis, have been normalized to a common height of 35 m by using the Hellmann formula [9]. Wind direction, which has no significance from the point of view of energy generation, is not considered in the present work.

Table 1. Description of measuring sites

Measuring site	Location	Landscape roughness class [10]	Measuring device	Height of measuring from the ground, m	Remarks
HRL	23°2.3′E 58°56.4′N	0	WICOM-C	35	Offshore site
KRS	22°29′E 58°12′N	1	USSR made	10	Measurements only in daytime
PRN	24°28′E 58°24′N	3	VAISALA	10	Started on 1 Oct. 1998
TLL	24°50′E 59°25′N	3	VAISALA	10	

The HRL site is located on an islet with no trees at the height of 4 m above the sea level (a.s.l.), the only obstacles to the wind are some low buildings. The KRS site is on a low peninsula covered with bushes about 300 m from the coast and about 8 m a.s.l. There are no obstacles in the path of the prevailing SW wind. The site PRN is situated in a low forest (<12 m) about 5 km from the coast and 15 m a.s.l. The TLL site is located on a limestone plateau covered with low forest, about 6 km from the coast and 50 m a.s.l. The wind sensors in PRN and TLL are at least 100 m away from any wind obstacles. The distances between measuring sites given in Table 2.

Table 2. Distances between measuring sites, km

Measuring site	HRL	KRS	PRN	TLL
HRL	–	121	64	70
KRS	121	–	118	191
PRN	64	118	–	114
TLL	70	191	114	–

The database for HRL and TLL is continuous from August 1 to December 31, 1998. The PRN data is available for the periods of 1 to 21 October and 10 November to 31 December, 1998. In the data recordings of the KRS non-automatic measuring device, interruptions occurred every night and no data is available for the Christmas period 25 and 26 December, 1998. These circumstances create limitations due to changing status of the group and the "marginal" data for each interruption cannot be used. The collected data has been statistically processed in EXCEL 7 and used to produce histograms (*HIS*) of the wind speed (Fig. 2) and the power increments (*ICR*) for the periods shown in Table 3.

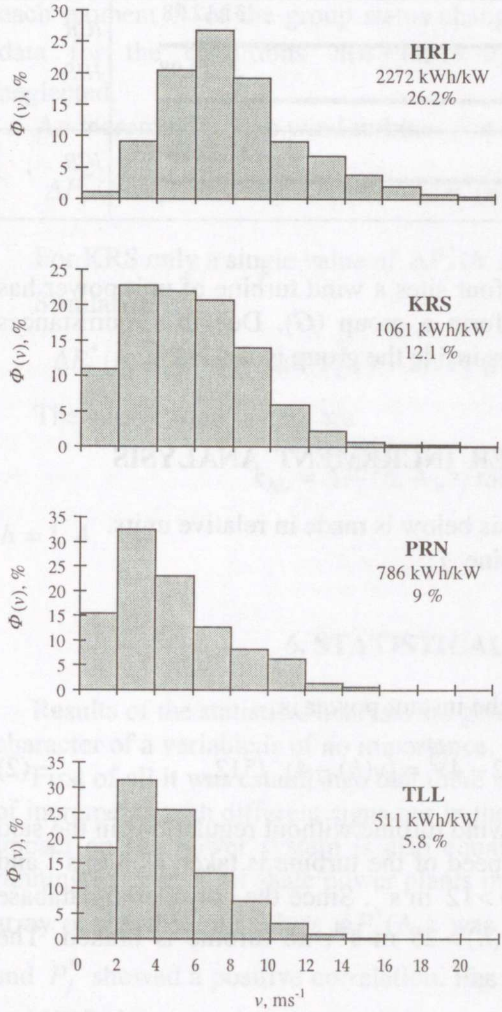

Fig. 2. Histograms of wind speed frequency $\Phi(v)$ at measuring sites; annual fictitious energy productions (kWh per a kW of the rated power) and the percentage of the implementation of the respective fictitious wind generation are also shown.

Table 3. Range of wind data processing for increments *ICR* and histograms *HIS*

Site	Period	
HRL	01.08.98 – 31.12.98	*ICR*
	21.09.98 – 17.11.98	*HIS*
KRS	01.08.98 – 01.08.98	*ICR*
	21.09.98 – 31.12.98	*HIS*
PRN	21.09.98 – 21.10.98; 10.11.98 – 31.12.98	*ICR*
	10.11.98 – 31.12.98	*HIS*
TLL	01.08.98 – 31.12.98	*ICR*
	21.09.98 – 31.12.98	*HIS*
G	01.08.98 – 31.12.98	*ICR*

Let us imagine that at each of the four sites a wind turbine of unit power has been installed and all (up to) four form a group (*G*). Due to circumstances described above the number of turbines inside the group is $2 \le n \le 4$.

5. METHOD FOR POWER INCREMENT ANALYSIS

If not defined otherwise, the analysis below is made in relative units.

For a single hypothetical wind turbine j:

if $v(h) > 12\ \mathrm{m\ s^{-1}}$, then $P_j^* = 1$,

if $v(h) < 4\ \mathrm{m\ s^{-1}}$, then $P_j^* = 0$.

In the range of $4 < v(h) < 12\ \mathrm{m\ s^{-1}}$ the instant power is

$$P_j^*(h) = (v(h) - 4)^3 / (12 - 4)^3 = (v(h) - 4)^3 / 512, \tag{2}$$

which corresponds to a conventional wind turbine without regulations in the said wind speed range. Here the starting speed of the turbine is taken as $4\ \mathrm{m\ s^{-1}}$ and the speed of power stabilization $v(h) > 12\ \mathrm{m\ s^{-1}}$. Since the considered database does not contain wind speeds for $v(h) > 25\ \mathrm{m\ s^{-1}}$, no turbine is braked. The instant power of the system is defined as

$$P_{\Sigma}^{*}(h) = \Sigma P_{j}^{*}(h) / n \qquad (3)$$

for all j where $P_{j}^{*}(h) > 0$.

A power increment for the wind turbine j at the instant h during an hour is

$$\Delta P_{j}^{*}(h, \Delta_1) = P_{j}^{*}(h+0.5) - P_{j}^{*}(h-0.5). \qquad (4)$$

The power increment for the group of n turbines at the instant h during an hour is

$$\Delta P_{\Sigma}^{*}(h, \Delta_1) = P_{\Sigma}^{*}(h+0.5) - P_{\Sigma}^{*}(h-0.5). \qquad (5)$$

Since according to the definition, $\Delta P_{\Sigma}^{*}(h, \Delta_1) = f(n)$, we cannot define it for each moment h of the group status change where $n = \text{var}$, and the "marginal" data for the conditions $n(h+0.5) \neq n(h)$ and $n(h-0.5) \neq n(h)$ must be neglected.

An increment for the wind turbine j at the instant h during four hours is

$$\Delta P_{j}^{*}(h, \Delta_4) = \text{average}(P_{j}^{*}(h+2) : P_{j}^{*}(h)) - \text{average}(P_{j}^{*}(h) : P_{j}^{*}(h-2)). \qquad (6)$$

For KRS only a single value of $\Delta P_{j}^{*}(h, \Delta_4)$ per day can be found.

Similarily,

$$\Delta P_{\Sigma}^{*}(h, \Delta_4) = \text{average}(P_{\Sigma}^{*}(h+2) : P_{\Sigma}^{*}(h)) - \text{average}(P_{\Sigma}^{*}(h) : P_{\Sigma}^{*}(h-2)). \qquad (7)$$

The suppression factors are

$$k_{\Delta \mathrm{h}} = \Delta P_{\Sigma}^{*}(h, \Delta_{\mathrm{h}}) / \max\{\Delta P_{j}^{*}(h, \Delta_{\mathrm{h}})\}, \qquad (8)$$

$h = 1, 4$.

6. STATISTICAL RESULTS

Results of the statistical analysis are given in graphical form. When the instant character of a variable is of no importance, we shall neglect the symbol "h".

First of all it was established that there was no difference neither in the values of increments with different signs nor in the regularity of their distribution. Their impact on the power system is also equal (both must be compensated by the running reserve of oil shale power plants in a similar way) and therefore the data array of the absolute values $\Delta P_{j}^{*}(\Delta_1)$ was analysed. It turned out that $\Delta P_{j}^{*}(\Delta_1)$ and P_{j}^{*} showed a positive correlation. Figure 3 shows this relationship for HRL and KRS sites.

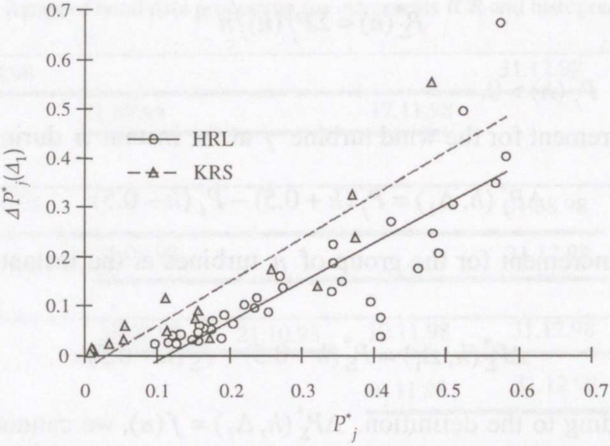

Fig. 3. Increment–power relation at the HRL and KRS.

From the calculated $\Delta P_j^*(\Delta_1)$ and $\Delta P_j^*(\Delta_4)$ data arrays, about 100 largest $\Delta P_j^*(\Delta_1)$ and about 50 largest $\Delta P_j^*(\Delta_4)$ were selected and the medium values of the increment suppression factor were determined for the observed cases (Fig. 4). On this basis the behaviour of a group with a bigger number of wind turbines can be assessed (shown graphically in Fig. 4).

From the point of view of the power system, the lower value of $k_{\Delta h}$ is more favourable. Bearing that in mind, wider geographical distribution of wind turbines gives greater effect by suppressing higher increments (short-term changes in wind speed): $k_{\Delta 1} < k_{\Delta 4}$ when $n = \text{const}$. An increase in the number of wind turbines in the system is beneficial, but this benefit decreases with the increase of the number of the turbines and approaches asymptotically a certain value.

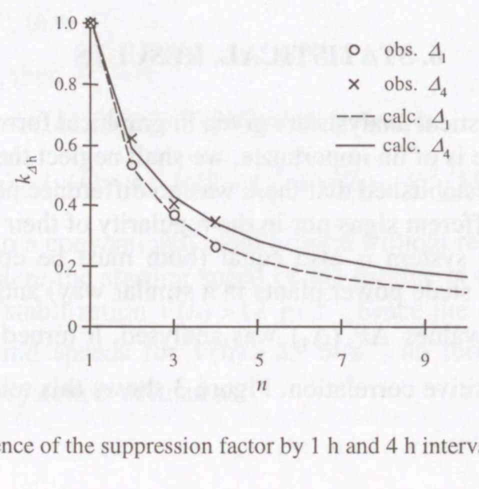

Fig. 4. The dependence of the suppression factor by 1 h and 4 h intervals on the system status.

7. FREQUENCY OF OCCURRENCE OF HIGH POWER INCREMENTS IN A GROUP OF DISSIPATED TURBINES

Database of the calculated $\Delta P_j^*(\Delta_1)$ allows calculation of the frequency of occurrence $\Phi(\Delta P^*)$ for different increments. Figure 5 shows that for the group with three turbines $G(3)$. For comparison, the same data for HRL is also presented. The frequency $\Phi(\Delta P^*)$ for a single turbine and the group is about the same at low values of ΔP^*, but differs significantly at high values of ΔP^*. To estimate the frequency of occurrence of $\Phi(\Delta P^*) = 100\%$ for the group, we have to extrapolate data obtained at low increments. The result depends very much on the character of the selected trend.

Table 4 shows frequency of occurrence for the 100% increment.

Table 4. Calculated frequency of occurrence of the 100% increment per one hour

Trendline	$\Phi(\Delta P^*)$, HRL	Calculated cases per year	$\Phi(\Delta P^*)$, $G(3)$	Increment suppressed, times
Power	0.1926	14.5	0.0253	7.5
Exponent	0.0819	7.2	0.00015	560

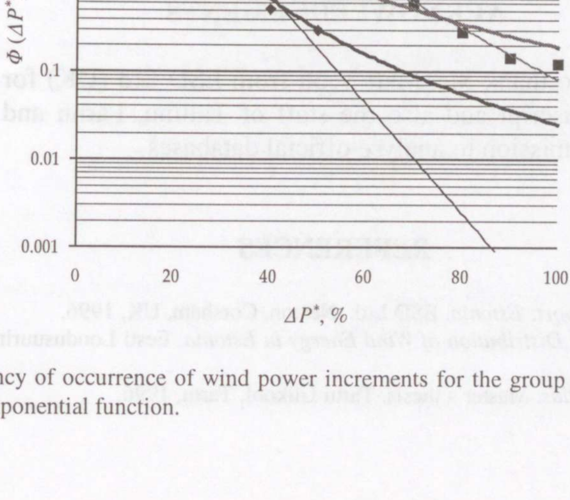

Fig. 5. Frequency of occurrence of wind power increments for the group of three $G(3)$; — power function, — exponential function.

We see that with the group mode performance the maximum increment is more suppressed than the average value of 100 higher increments (Fig. 4). Calculated number of high increments per year, compared with the six cases observed at HRL during a year from 21.09.97 to 20.09.98 shows the validity of the exponential trend, but the suppression of 560 times seems to be an exaggeration, caused by the short database of $G(3)$ performance. The methodology to measure the effect for the suppression of the increment can be evidently improved.

8. CONCLUSIONS

Based on this investigation, in spite of certain weaknesses of the database used (the Hellmann calculation formula is valid for the average wind values but not exactly for instant values, the data arrays for different turbines are of different length, interruptions in the data array are considered as windless time), some essential conclusions can be drawn.

1. For a power system, wider geographic distribution of wind turbines (or wind farms) to several sites is expedient.
2. The number of such sites does not need to be big, 4–6 different sites is sufficient.
3. The obtained suppression of an average power increment for one hour may reach 3–4 and frequency of the occurrence of big increments decreases significantly.
4. The probability of 100% power increment per one hour in the group remains still higher than zero.

The authors see that it is necessary to continue the work in this field to find an answer to some unclear questions. This would entail repeating this work with a synchronized wind monitoring system designed specifically for this investigation, which would improve the reliability of the conclusions.

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HAJUTATUD TUULETURBIINIDE TALITLUS

Teolan TOMSON ja Maire HANSEN

Eesti energiasüsteem baseerub inertsetel soojuselektrijaamadel. See tekitab probleeme võimsuse kiire muutusega tuulegeneraatorite juurutamisel. Artiklis on Harilaiu, Kuressaare, Pärnu ja Tallinna tuulte sünkroonset andmebaasi kasutades analüüsitud, kuidas tuuleturbiinide grupitöö lubab tuule kiiruse muutusest tingitud summaarse võimsuse muutusi maha suruda. Probleemi uudsuse tõttu pole veel väljakujunenud metoodikat selle efekti mõõtmiseks, mistõttu töö sisaldab kahe lähenemisviisiga leitud arvväärtusi, mis mõnevõrra lahknevad. Uurimuse kohaselt annab tuuleturbiinide geograafiline hajutamine suuremat tulu just võimsuse lühiaegsete muutuste mahasurumisel ja see efekt suureneb turbiinide arvu suurendamisega grupis. Tuuleturbiinide grupi võimsuse 100-protsendist muutust (ühe tunni jooksul) pole võimalik vältida, kuid selle esinemise tõenäosust võib vähendada kuni kahe suurusjärgu võrra.