GEOGRAPHICALLY DISPERSED WIND TURBINES ON THE WEST-ESTONIAN COAST

Teolan Tomson and Ants Nõva[1]

ABSTRACT

Estonian farms are connected to the common grid practically for 100%. Therefore efforts to improve the share of renewable energy resources in the agriculture must consider the impact on the common grid. Estonia is rich of wind energy, but its random character and rapid changes in velocity (causing high wind power increments) create problems for the wind turbines to be matched with the existing power supply. The geographical dispersion of wind turbines will help to reduce their total wind power increment and impact on the common gird. This effect has been studied by two different approaches at four separated sites on the Estonian western coast. Both methods show that the resulting power increment can be suppressed up to 3 – 5 times if the number of sites exceeds 3 – 5.

Key words: Increment of wind power, dispersed turbines.

INTRODUCTION

Almost all Estonian farms are connected to the common grid. Therefore efforts to improve the share of renewable energy sources in the agriculture must consider the impact on the common grid since there is no specific electrification for agriculture.

In an electrical grid a balance of generated and consumed power is required for any instant of time. Generated power of a wind turbine follows (in its range of performance) the wind velocity, which may have rapid changes. Estonian *oil-shale* thermal power plants are equipped with big 200 MW power blocks with a thermal transient time ~24 hours each. These power blocks can control the balance of power in the grid in parallel with wind turbines when operated in the running reserve only. The running reserve requires thermal power plants to perform in the transient regime resulting in higher pollution levels that creates a problem in complying with the Kyoto protocol. Estonia has no fast regulated hydro or gas fired power plants, commonly used for the wind power balance in the electrical grid. Due to the described peculiarities, matching of wind turbines with the existing grid will evoke problems. We shall show how these problems can be reduced if we do not concentrate wind turbines in a single site, but distribute them over a wider geographical area.

DYNAMIC PERFORMANCE OF A WIND TURBINE

Most of conventional wind turbines have a cubical dependence of power-velocity characteristics $P(v)$ within their common performance range $v_{\mathrm{start}}<v<v_{\mathrm{stabil}}$ (Bennert, 1991).

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Usually the start-up velocity is $v_{\text{start}} = 4\ \text{m s}^{-1}$ and the velocity of output power stabilization $v_{\text{stab}} = 12\ \text{m s}^{-1}$. Accordingly, the instant value of the wind power $P(h)$ can be calculated

$$P(h) = P_{\text{rated}} \cdot (v(h) - v_{\text{start}})^3 / (v_{\text{stab}} - v_{\text{start}})^3, \tag{1}$$

where wind velocity $v(h)$ is actually a (mostly) random process.

If $v(h) < v_{\text{start}}$, then $P(h) = 0$ and
if $v(h) > v_{\text{stab}}$, then $P(h) = 1$.

It is expedient to analyze the performance of a wind turbine in relative units
$P^* = P(h)/P_{\text{rated}}$. In this case

$$P^*(h) = 1 \cdot (v(h) - v_{\text{start}})^3 / (v_{\text{stab}} - v_{\text{start}})^3). \tag{2}$$

For any change in the wind velocity Δv within the performance range $v_{\text{start}} < v < v_{\text{stabil}}$ an unequal change of wind power ΔP corresponds. Due to the said characteristic, the changes of wind velocity (increments) are damped for low (and very high) average values of wind velocity, but amplified when the average value of wind lies in a range $8 < v < 10\ \text{m s}^{-1}$ (approximately). Figure 1 shows this behavior for two equal wind velocity increments $\Delta v_2 = \Delta v_1$ at different average values. We can see that the corresponding wind power increments $\Delta P^*_2 > \Delta P^*_1$ are not equal to the said wind velocity increments and any (high) power increment influences the performance of electrical grid. Low wind power increments have no meaning.

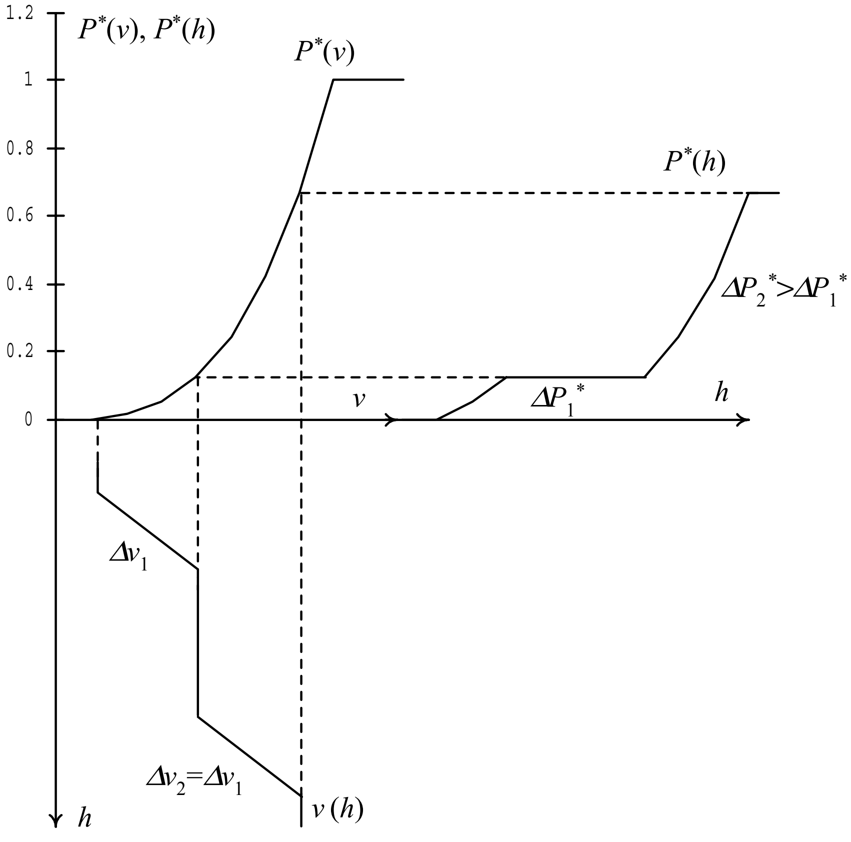

Figure 1. Equal wind velocity increments are transformed into unequal power increments at different average values of wind velocity

Also, the relative power increment ΔP^* for an instant time h and time-step Δh can be determined for the j-th turbine as
$\Delta P_j^*(h) = P_j^*(h + \Delta \mathrm{h}/2) - P_j^*(h - \Delta \mathrm{h}/2)$. (3)

Here we consider that in the group up to $n = \Sigma j$ turbines may perform in parallel. For a fixed group of n equal turbines their increment is defined

$$\Delta P^*_{\Sigma}(h) = \Sigma \Delta P_j^*(h)/n. \quad (4)$$

If the wind velocity changes should happen synchronously, $\Delta P^*_{\Sigma}(h) = \Delta P_j^*(h)$ no effect can be observed, but in fact the wind fronts are time shifted (Bernow et al, 1994) and therefore $\Delta P^*_{\Sigma}(h) < \Delta P_j^*(h)$ in most cases. We shall illustrate a real wind front delay in the Estonian Monsoon Archipelago in figure 2 (Tomson and Hansen, 2000) for the sites Harilaid "H" and Tahkuna "THK" (with real wind turbine performance) with the distance of 35 km between them (fig. 3).

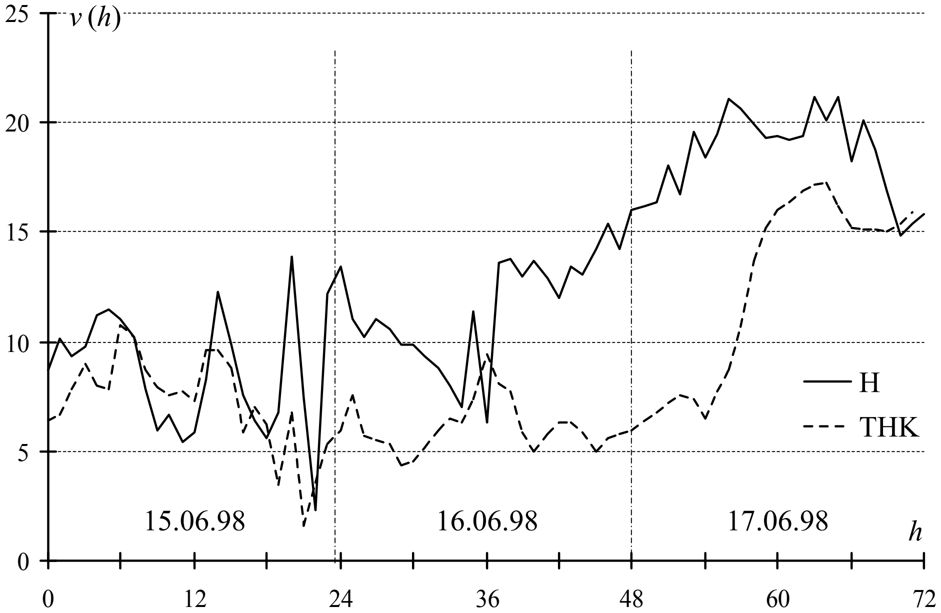

Figure 2. The delayed wind velocity fronts at the Harilaid and Tahkuna sites

Below we shall consider the time-step for the increment definition $\Delta h = 1$ h (one hour) like (Durstewitz et al., 1997).

THE SYNCHRONIZED DATABASES

To be sure of the possibility to reduce the total power increment for a geographically distributed wind turbine group, a preliminary investigation was made. The synchronized wind velocity $v(h)$ databases with the monitoring interval of 0.5 h on the Harilaid islet and in the coastal airports of Tallinn, Pärnu and Kuressaare were investigated in the period of 1 Aug. – 31 Dec., 1998. The average distance in this group is ~110 km and Harilaid is in fact an offshore site where the wind resource is prevailingly higher than in other locations.

We can assume that in each location a similar wind turbine with the equal specific capacity (1 kW or 1 MW etc.) is installed.

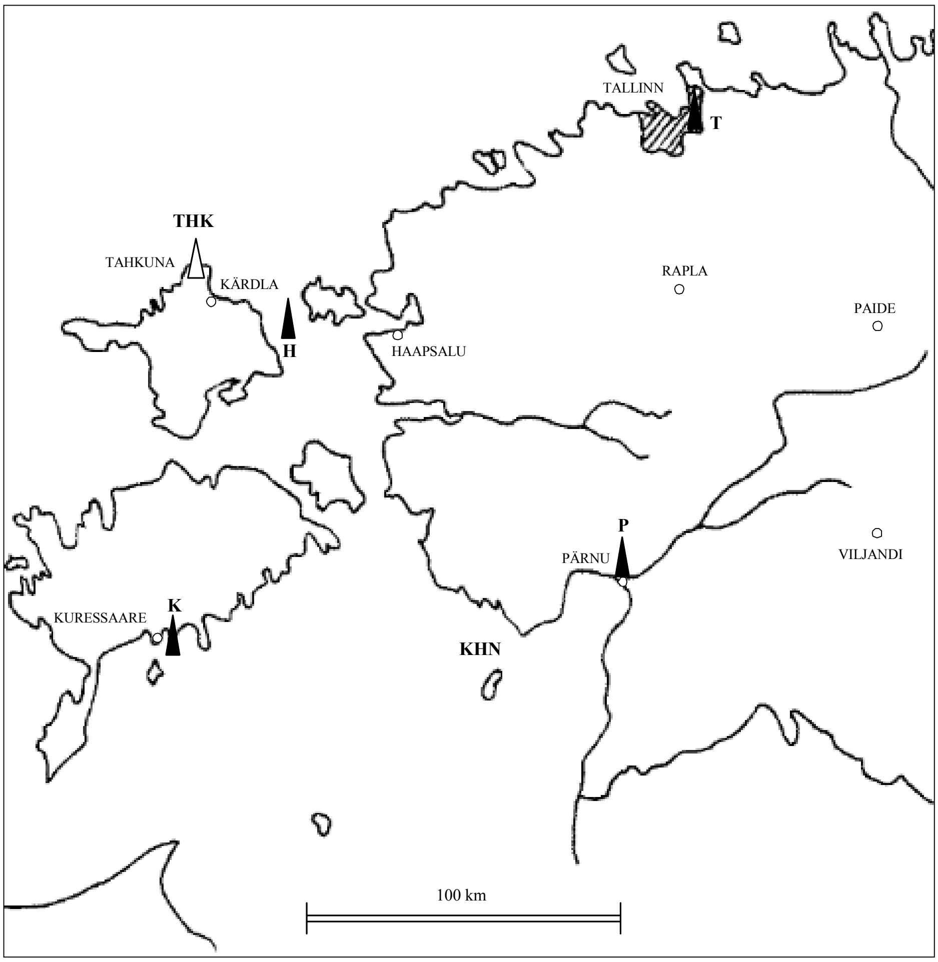

Figure 3. Synchronously investigated sites on the Estonian western coast

METHODS FOR THE POSITIVE EFFECT EVALUATION

Authors see two possible approaches here.

1. The first approach is to compare the values and order of occurrence of big power gradients. Based on databases of velocities, the power gradients ΔP^*_j for each location and the total group were calculated by the following formulas.

For a single *j*-d wind turbine, its power increment is calculated with (2) and (3).

For the group of turbines, the power increment is calculated differently from (4) due to varied number of turbines n=var in the group.

$$\Delta P^*_\Sigma = P^*_\Sigma(h+\Delta_h/2) - P^*_\Sigma(h-\Delta_h/2), \text{ where} \tag{5}$$

$$P^*_\Sigma = \Sigma P_j / \Sigma j(h). \tag{6}$$

It means that P^*_Σ depends on the status of the system, i.e. how many wind turbines are in operation at the said instant of time and we cannot estimate ΔP^*_Σ for any marginal instant when the status of the system is changing. The lack of data (Kuressaare for the night time) is considered as “wind turbine not operating”.

The investigation shows that positive and negative wind velocity and power increments have practically equal (average) values and distribution principles (fig. 4). These diagrams are based on the time-series at the Harilaid site from Aug. 1, till Dec. 31, 1998 (22,025 observations). $\Phi(\Delta P^*)$ and $\Phi(\Delta v)$ are the frequencies of occurrence (relative share in %) of the corresponding variables. The numbers on the x-axis are medians of the corresponding intervals. Example: “0.65” means $0.6<\Delta P^*<0.7$ and $6<\Delta v<7$ m s^{-1}. Due to the said symmetry, it is feasible to analyze the absolute values of increments (as their impact on the grid is equal also).

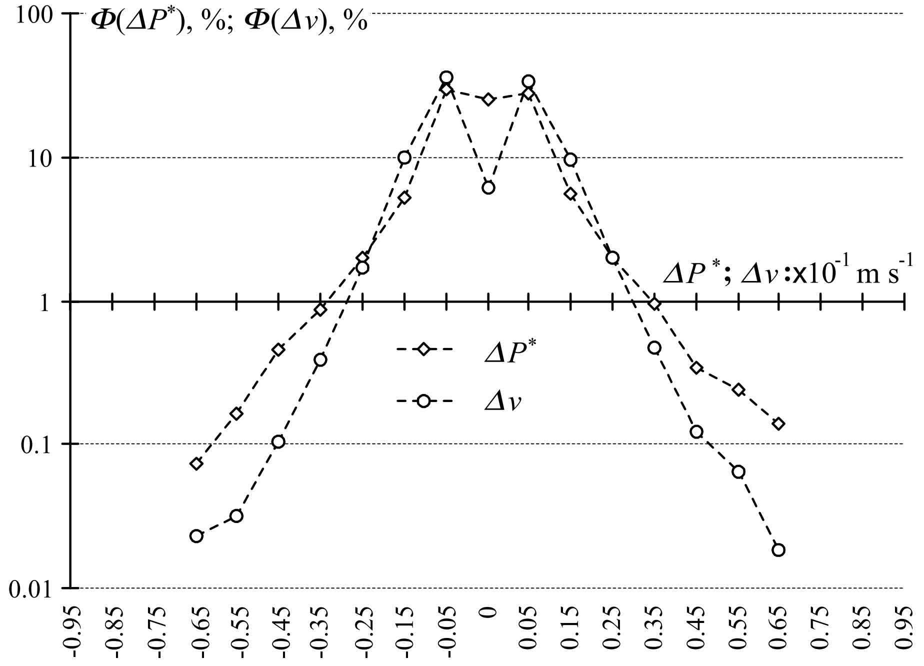

Figure 4. Share of relative power and wind velocity increments at the Harilaid site 1.08 –31.12.98

Figure 5 shows the first ten highest k increments ΔP^*_j (at the synchronized time instant). In this figure we use the following symbols for the site indexes “*j*”: H – Harilaid, K – Kuressaare, P – Pärnu, T – Tallinn and S – the whole group of them ($n=4$). The distribution order for a reduced group (three or two sites $n<4$) is similar, but not equal. We can see that for any possible k, $\Delta P^*_\Sigma < \mathrm{Min}(\Delta P^*_j)$, $j \in \{$ H, K, P, T$\}$. is always valid Reduction of high increment in a group has been proved by such a method, but we cannot measure it.

2. The second approach is to calculate the power increment suppression coefficient, which allows to evaluate the effect of the group mode performance:

$k_\Delta = \Delta P^*_\Sigma / \mathrm{Max}\,(\Delta P^*_j)$ where

$\mathrm{Max}\,(\Delta P^*_j)$ is the highest single increment in the group at the current instant of time. It is feasible to compare the group just with the maximum in the group, because concentrated wind electricity generation involves always emergence of a natural increment being one among others in the group.

From $\{\Delta P^*_j\}$ we shall group the synchronized data according to the status of the system ($\{\Sigma j(h)=2\}$, $\{\Sigma j(h)=3\}$ and $\{\Sigma j(h)=4\}$). In each data group we shall select the synchronized data $\{\mathrm{Max}\ \Delta P^*_j\}$ by their descending value and calculate k_Δ for the first 100 higher values since the low values of ΔP^*_j can be neglected (no problem with them). The calculated average values (for the first 100) in Fig. 6 show that the increment suppression coefficient depends on the number of the units in the group of turbines Σj. It is not necessary to use a big number of dissipated turbines $\Sigma j > (4\ldots6)$ since the effect of reducing k_Δ decreases gradually.

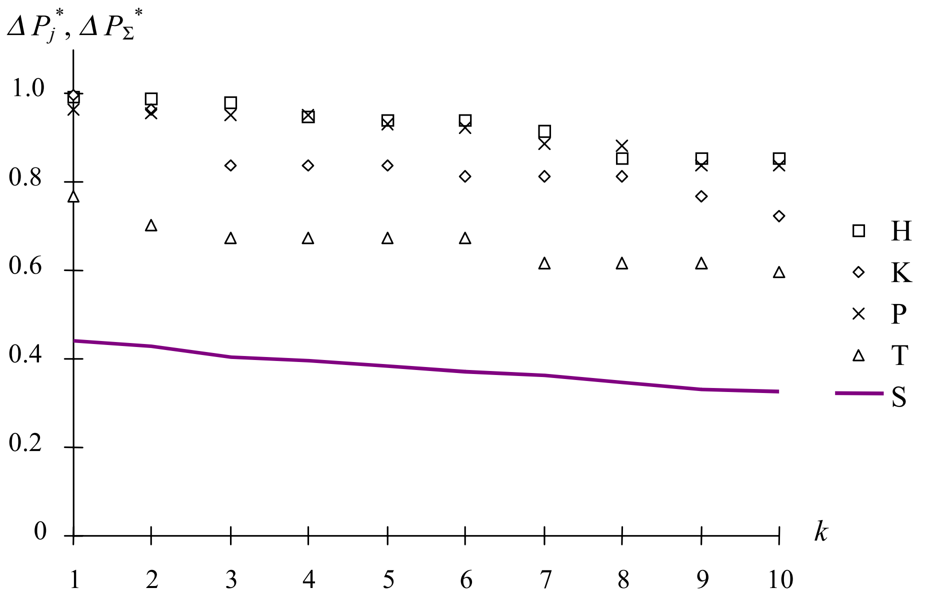

Figure 5. First ten highest synchronous increments for each single turbine and the group of turbines S

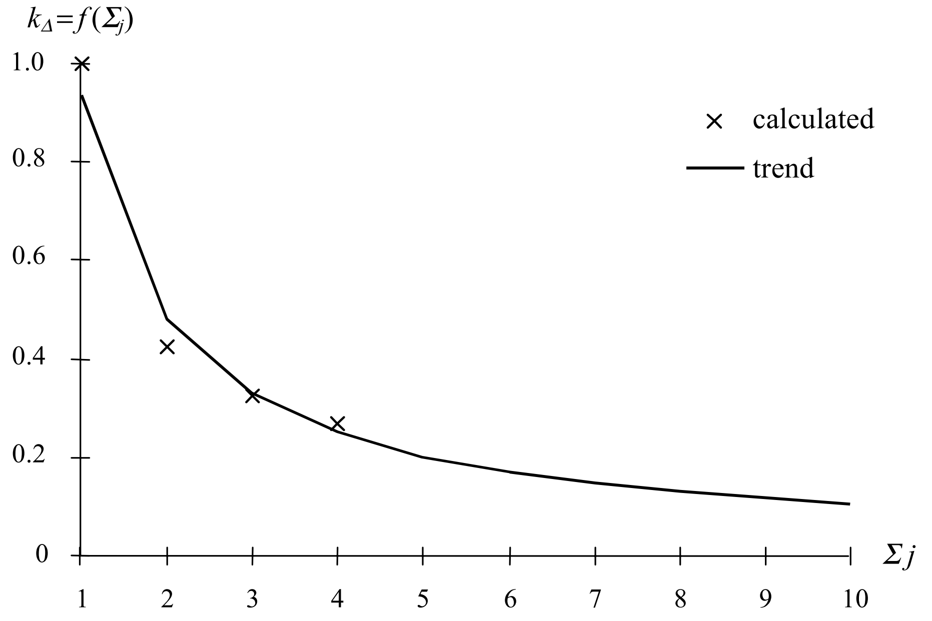

Figure 6. Coefficient of the power increment suppression as a function of the number of turbines in the group $n = \Sigma j$

FREQUENCY OF HIGH POWER INCREMENTS OCCURRENCE FOR A GROUP OF DISPERSED TURBINES

Database of the calculated ΔP^* allows to calculate the frequency of their occurrence $\Phi(\Delta P^*)$. Under the frequency of occurrence $\Phi(\Delta P^*)$ we mean the share (relative number in %) of increments for their different range

$\{0 < \Delta P^* < 10\%\} / \forall \{\Delta P^*\}$,
$\{10\% < \Delta P^* < 20\%\} / \forall \{\Delta P^*\}$ and so on.

The frequency of occurrence $\Phi(\Delta P^*)$ can be assessed for a single turbine or for the whole (n=var) group. Figure 7 shows that for the group with the number of turbines "S = 3" and "S = 4", the frequency of occurrence is practically coinciding. For the comparison, we shall present the same variable for the Harilaid site "H". The frequency of occurrence for the group $\Phi(\Delta P^*_\Sigma)$ at the low values of the increment ΔP^* is nearly equal to that of a single turbine, but differ at the high values of the increment significantly. To estimate the frequency of occurrence of 100% increment for the group, we have to implement a trend line that is based on the low value of increments. The result depends very much on the characteristics of the selected trend. The automatically generated (by the EXCEL programmed) exponential trend (fig. 7) allows to forecast the possible occurrence frequency of the 100% increment: 0.19% for Harilaid and 0.025% for the group of three turbines. If we compare the said prognosis with the real number of 100% increments during a year 1997/98 at Harilaid (Tomson and Hansen, 2000), we can see the prognosis giving much higher (pessimistic) value. This difference may be explained with the fact that for the prognosis we used the available database for the winter season only and the whole year has more modest average wind conditions and more modest increments too.

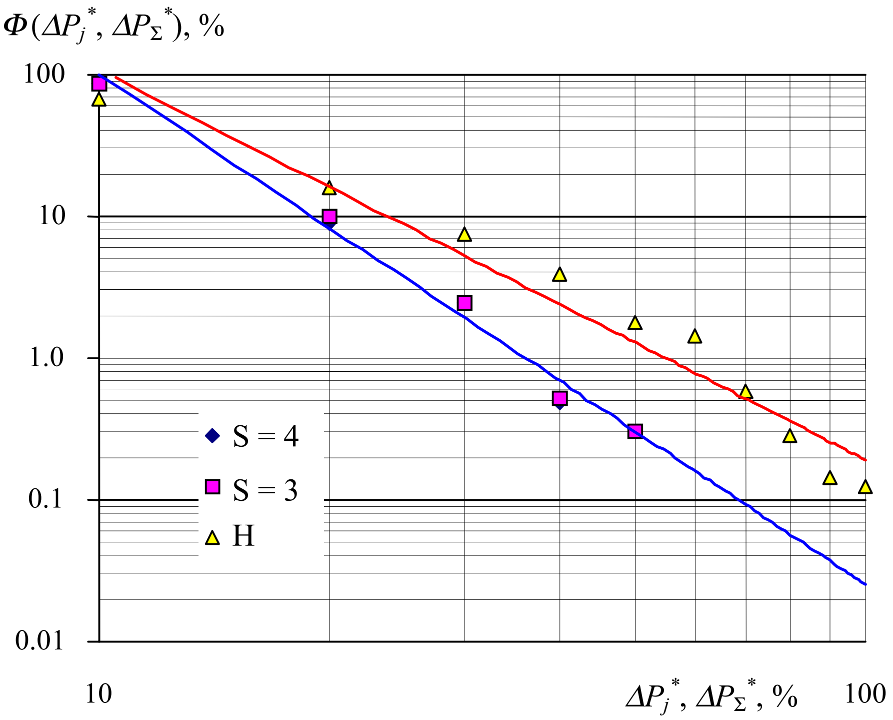

Figure 7. Frequency of occurrence of wind power increment for the group of 3 (and 4) turbines and a single unit at the Harilaid site

CONCLUSIONS AND RECOMMENDATIONS

The preliminary study of synchronized wind data on the western coast of Estonia leads to the following conclusions:

- Positive and negative wind velocity and wind power increments have equal (average) values and distribution order.
- From the point of view of the power system, the geographical dispersion of wind turbines is feasible.
- The number of sites may be modest (4 – 6 separated locations seems to be sufficient).
- The probability of high power increments in a group will decrease several times, but will still remain higher than zero.

We consider that the investigation has not been completed. The used databases differ: the data on Harilaid and Tallinn were complete in the range of Aug. 1, to Dec. 31, 1998, but for Pärnu the database was less extensive and in Kuressaare no data for night hours was available. Therefore the present investigation should be evaluated as a preliminary attempt. The question how the distances within the group influence the increment suppression is also unsolved.

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