Estimation of real emissions reduction caused by wind generators

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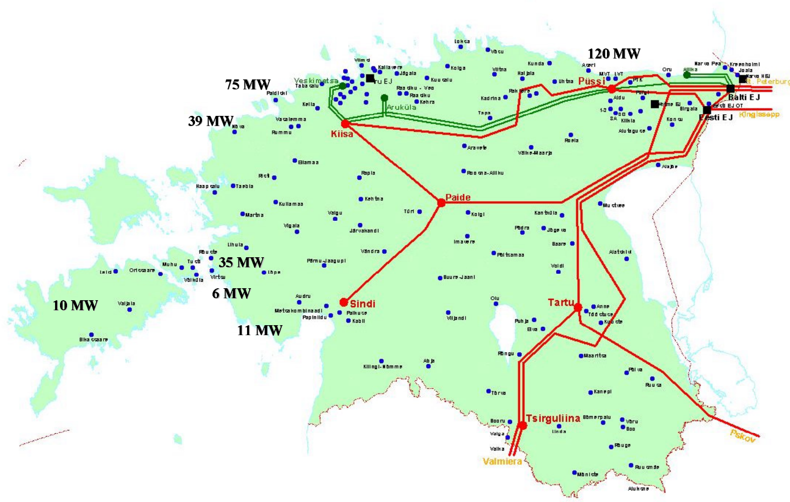
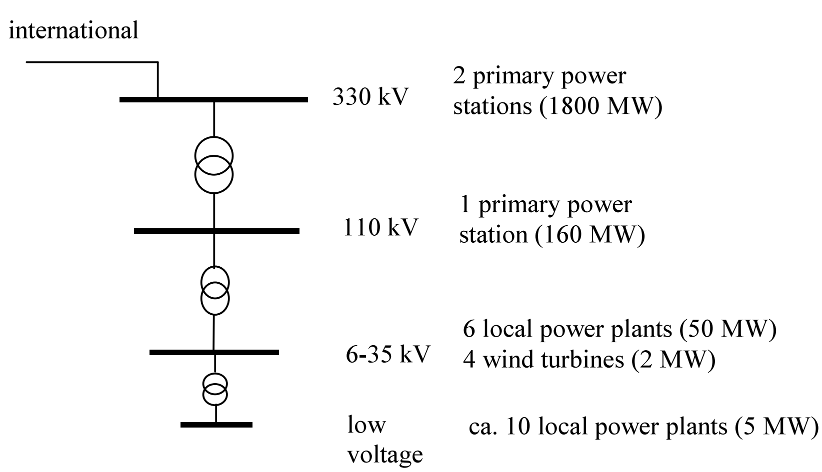
Reasons of interest to wind power in Estonia

- A target set by EU to increase the share of RES in the electricity production up to 5,1% from gross domestic electricity consumption
- Good wind conditions, long coastline, many islands
- Purchasing obligation of electricity from RES
- Feed-in tariff related to the production price of fossil fuel power plants (increasing)
- Incentives to start local manufacturing of wind turbines and their parts

Current applications for connection of wind farms



Structure of the electric network of Estonia



Problem of balancing of wind power fluctuations (I)

- Wind power plants are almost uncontrollable
- Integration of windmills with the existing power system depends on the size and structure of concrete power system and on the capacity of links with neighbouring systems
- Until all the fluctuations of wind power can be compensated with the hydro power plants, the integration of windmills does not trouble the existing system too much and the environmental gain is linearly proportional to the produced amount of electricity

Problem of balancing of wind power fluctuations (II)

If the power systems contains only thermal power plants or if the installed capacity of windmills exceeds the regulation capacity of hydro plants:

- As the CHP plants usually follow the thermal load, the condensing power plants must participate in the compensation of wind power fluctuations
- Large condensing units cannot be switched on and off frequently and for a short period and their speed of increasing and decreasing of power is limited

Problem of balancing of wind power fluctuations (III)

- Most suitable thermal plants for the load regulation and fast reserve capacity are the gas turbines.
- If someone wants to introduce large amount of wind power then the power regulating range and speed of the existing plants must be also extensive.
- Operating a thermal plant with and without the need to compensate the fluctuations of wind power is similar to the running of a car in the city and on the highway, respectively. Fuel consumption of a car can be even double in the city comparing with the highway.

Problem of balancing of wind power fluctuations (IV)

- The thermal power production without wind generators is equal to the load and it is distributed among the thermal power plants according to the optimality criterion and using static input-output characteristics.
- When the wind power appears in the system, thermal power stations have to keep constantly additional spinning reserve capacity equal to the maximum total power of windmills. This makes the thermal plants run inefficiently and increases fuel consumption (emissions).
- Under the fast changes of wind power, the real fuel consumption will increase even higher. The actual operation points of thermal plant will form a curve that is similar to a hysteresis loop. This is the dynamic fuel consumption curve.

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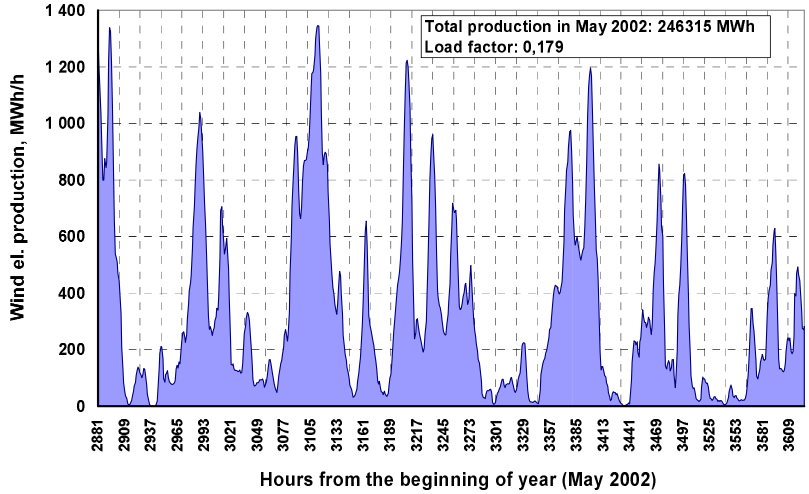
Wind generated electricity production in Western Denmark in May 2002



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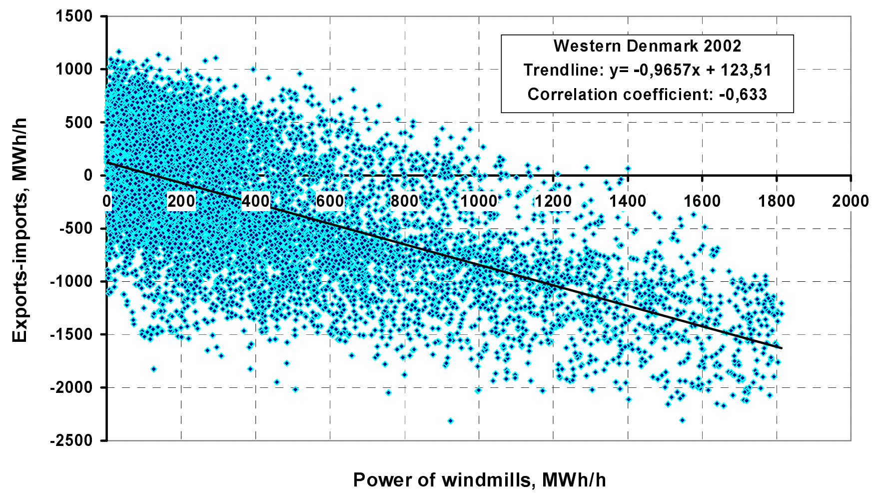
Denmark exports wind generated electricity



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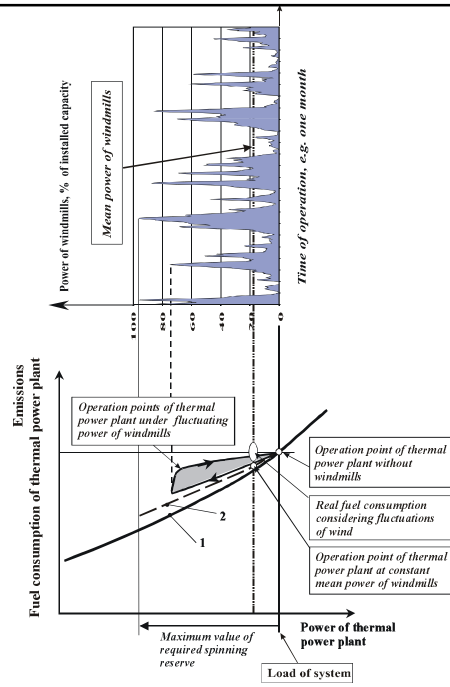
Explanation of wind energy balancing and fuel consumption increase problem



1 –initial fuel consumption (or cost or emissions) curve of thermal power plant,
2 – the same curve that considers additional requirement for spinning reserve capacity due to wind generators

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A method for calculation of real environmental effect of wind power (I)

- To calculate the emissions from power system, we originate from the problem of optimal load planning
- The objective of optimal load scheduling in power system with thermal power plants and wind generators is the minimization of the total fuel cost (can be also fuel consumption or emissions) at a certain time interval

$$\min_{P_T} \sum_{k \in K} \sum_{i \in I} C_{ik}(P_{Tik}) \cdot \Delta t_k$$

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A method for calculation of real environmental effect of wind power (II)

- power balance equations

$$P_{D\Sigma k} + P_{Lk}(P_{Tk}, P_{Wk}, P_{Dk}) - \sum_{i \in I} P_{Tik} - P_{W\Sigma k} = 0 \qquad k \in K$$

- power limitations of thermal plants

$$P_{Tik}^{-} \le P_{Tik} \le P_{Tik}^{+} \qquad i \in I \qquad k \in K$$

- spinning reserve constraints

$$\sum_{i \in I} P_{Tik}^{-} \le \sum_{i \in I} P_{Tik} - P_{W\Sigma k} \le \sum_{i \in I} P_{Tik}^{+} - P_{Rk} \qquad k \in K$$

A method for calculation of real environmental effect of wind power (III)

i – thermal plant index, ;

k – time subinterval index, ;

P_{Tik} – active power, generated at i^{th} thermal plant in k^{th} subinterval;

C_{ik} – fuel cost of i^{th} thermal plant in k^{th} subinterval;

Δt_k – duration of k^{th} time subinterval;

$P_{D\Sigma k}$ – total active power demand of power system in k^{th} subinterval;

P_{Lk} – total transmission losses in k^{th} subinterval;

P_{Wk} – vector of active powers of wind generators in k^{th} subinterval;

P_{Dk} – vector of power system loads in k^{th} subinterval;

$P_{W\Sigma k}$ – total wind power generation in k^{th} subinterval;

P_{Rk} – spinning reserve requirement in k^{th} subinterval;

x^{-}, x^{+} – lower and upper limits of x, respectively.

A method for calculation of real environmental effect of wind power (IV)

In the simplest case optimal powers of thermal plants are determined by equations

$$b_{1k} = b_{2k} = \ldots = b_{ik} \qquad k \in K$$

where

$$b_i(P_{Ti}) = \frac{\partial C_i(P_{Ti})}{\partial P_{Ti}}$$

incremental (marginal) cost characteristic of i^{th} power plant

A method for calculation of real environmental effect of wind power (V)

- The fuel costs and consumptions and emissions can be read from the corresponding characteristics of thermal plants using calculated optimal powers.
- Reduction of emissions from power system due to wind energy use is calculated as the difference of emissions between optimization results with and without wind power.

Initial information is incomplete

In the real life, the optimization process has to be implemented under incomplete information.

The main uncertainty factors are:

- the total active power demand of power system $P_{D\Sigma k}$
- the active powers of wind generators and total wind power generation
- the dynamic input-output characteristics of thermal plants $C_{Tik}(P_{Tik}, Z_{Tik}, k)$ and $Z_{Tik+1}(P_{Tik}, Z_{Tik}, k)$
- the random deviations of actual values of power plant generations from the planned values.

Need to use dynamic input-output characteristics of thermal plants

- If we deal with the necessity of compensation of wind power fluctuations with the thermal power plants, the fuel cost characteristics must be considered as the dynamic ones.
- Under dynamic characteristics the fuel cost in the time interval *k+1* depends on the power in the interval *k*, power in the interval *k+1*, and speed and direction of the change of power.
- The use of dynamic characteristics makes the optimization task highly complicated (differential equations).
- Usually the dynamic fuel consumption characteristics are not known.

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Simplified solution

- Calculation of additional fuel consumption (cost, emissions) for keeping maximum amount of spinning reserve and determining of corresponding new point of fuel consumption characteristic.
- Parallel shift up of the initial characteristic to the new position and use of the new characteristic as rough substitute of the dynamic fuel consumption curve.

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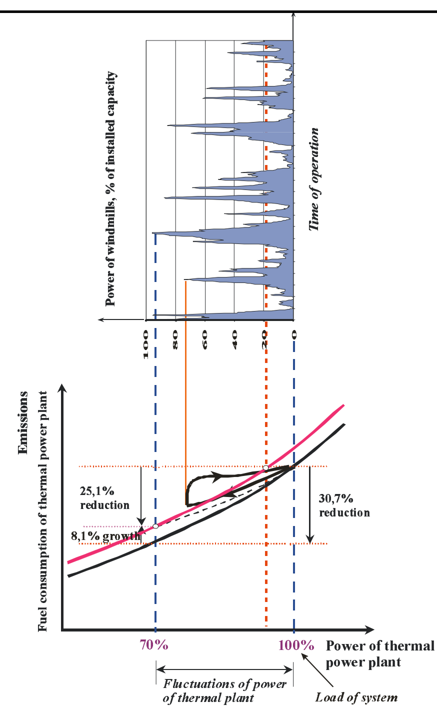
Results of calculation of fuel consumption increase on the base of Estonian power system and Danish wind energy data



Conclusions

- Participation of thermal power plants in keeping the reserve capacity for wind turbines and in compensation of the fluctuations of wind power increases the fuel consumption and emissions substantially.
- Linear methods of calculation of emission reductions from wind energy use cannot consider this increase and therefore special methods for correct accounting of environmental gain have to be elaborated.