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Acoustic control of wind farms

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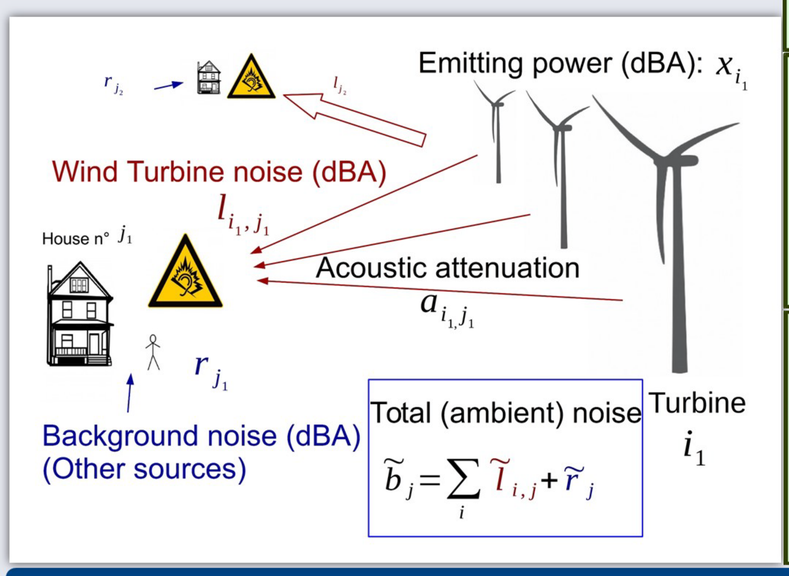
Acoustic Curtailment

Maximize electric power production over time under acoustic constraints.

- Issues : worst-case assumptions and control based on weather parameters only



Acoustic emergence:

$$\tilde{e}_j = \frac{\sum_i \tilde{l}_{i,j} + \tilde{r}_j}{\tilde{r}_j}$$ (linear formulation)

or

$$e_j = b_j - r_j$$ (Decibel formulation)

Acoustic constraints:
for each measurement point j:

$$e_j \le T_1$$

or

$$b_j \le T_2$$

Acoustic constraints in practice:
for each measurement point j, & each homogeneous class o:

$$median_o(b_j) - median_o(r_j) \le T_1$$

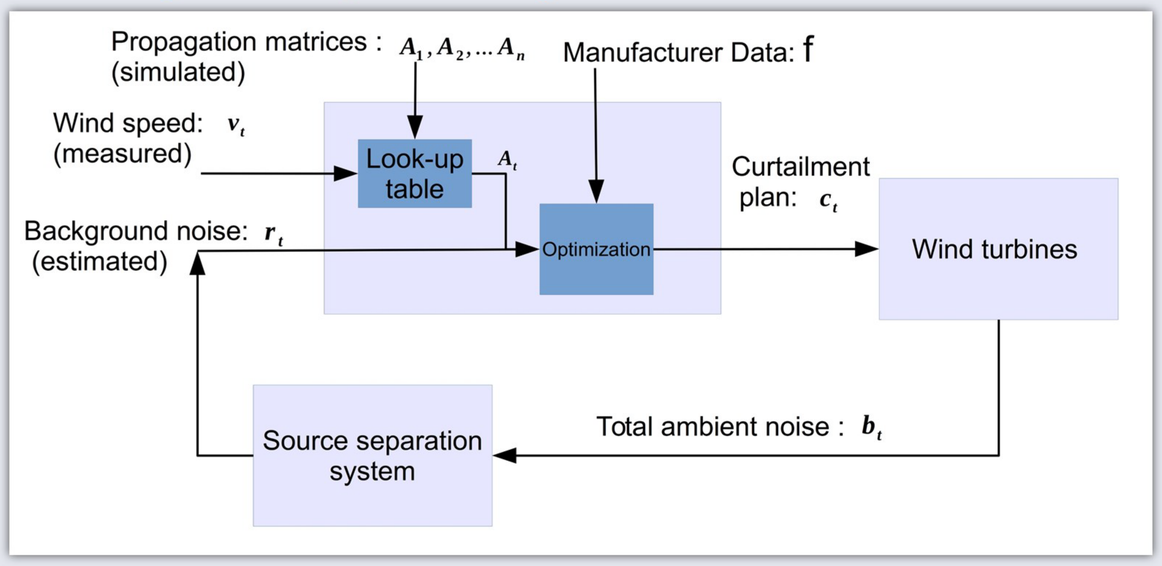
and $$median_o(b_j) \le T_2$$

Proposed Approach

Real-time control system based on source separation.

Our work focuses on the control model.

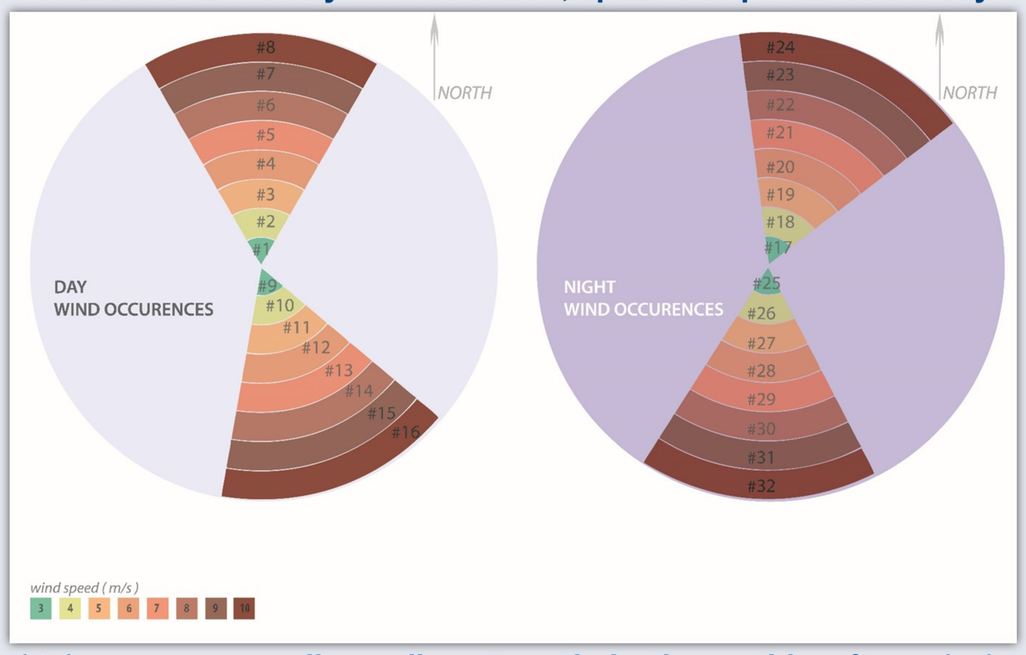
- Background noise estimated by source separation
- Model based on a look-up table of the propagation data
- Manufacturer power curves used to compute the optimal curtailment plan
- Resulting curtailment plan sent every 10 minutes to the SCADA



Optimisation Unit

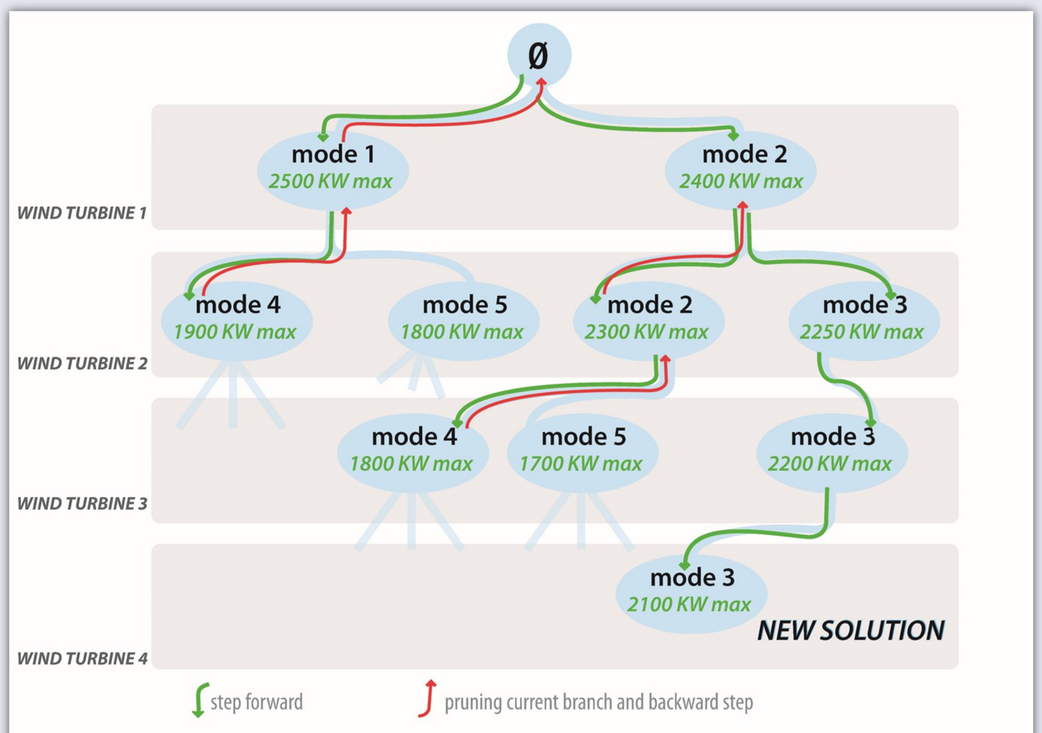
Every 10 minutes, the current wind measure is classified.

The classes are defined by wind direction, speed and period of the day.



We obtain a **convex non linear discrete optimization problem** for each class:

$$\begin{cases} \max_{\tilde{\mathbf{x}} \in \tilde{\mathbf{r}}_v(\mathcal{C})^I} \sum_{i=1}^{I} \mathrm{f}(\tilde{x}_i) \\ \tilde{\mathbf{A}}^T \tilde{\mathbf{x}} \le \mathbf{q} \end{cases}$$

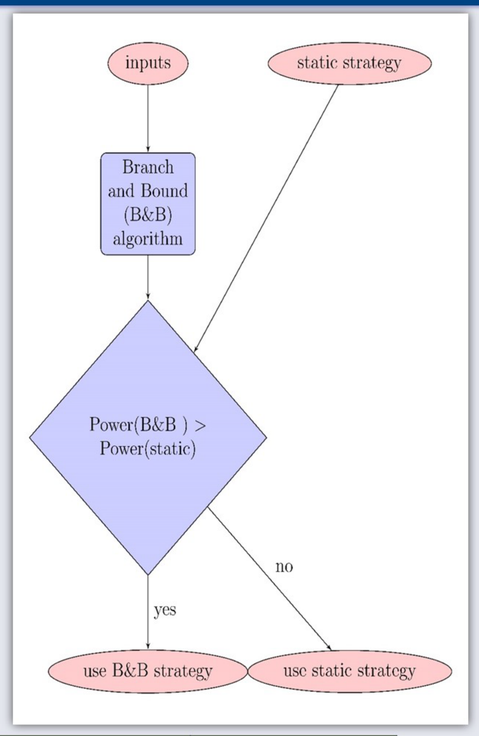


Exemple of one iteration of the branch and bound algorithm starting with a solution of 2000 KW

- The optimization problem is solved by a **Branch and Bound algorithm**
- Nodes are labelled with an **upper bound** of the objective function
- Upper bounds are obtained from a **continuous relaxation problem**

Results

- **Limitation of the instantaneous emergence may induce a gain loss** because of the medians used in practice.
- **The proposed solution uses the current static strategy to fulfill the median criterion *a posteriori***



Production power compared to full power	Wind farm 1		Wind farm 2		Wind farm 3	
	day	night	day	night	day	night
Full-power Strategy	0	0	0	0	0	0
Static strategy	2.2	42.4	0	63.6	0	0
Instantaneous criterion limitation	9.2	34.4	3.8	56.3	0	1.2
Proposed control	1.4	30.7	0	53.6	0	0

Acoustic excesses of the median criterion (% of time)	Wind farm 1		Wind farm 2		Wind farm 3	
	day	night	day	night	day	night
Full-power Strategy	39	91	1	100	0	1
Static strategy	30	33	1	31	0	1
Instantaneous criterion limitation	1	0	4	0	1	1
Proposed control	30	31	1	31	0	1

Conclusions

- **We developed an optimal algorithm to limit the instantaneous noise attributed to wind turbines by inhabitants around wind farms.**
- **We proposed a solution that fulfills the criterion used in practice with a consistent electrical gain (about 5%).**
- **Laws will have to be adapted to the new control possibilities.**

[1] Pierre Bonami, Mustafa Kilinc, and Je Linderoth. Algorithms and software for convex mixed integer nonlinear programs. In Mixed integer nonlinear programming. Springer, 2012.

[2] Dorit S. Hochbaum. A nonlinear knapsack problem. Operations Research Letters, 1995.