Acoustic control of wind farms

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1 Introduction

For the past few years, preventing people living around wind farms from noise pollution has been one of the main concern of numerous countries in the world. In some countries including France, a criterion called acoustical emergence is used as a measure of acoustic noise discomfort and a maximal admissible value was introduced. The acoustic emergence is fundamentally the acoustic energy gain brought by the wind turbines to the background noise perceived around the farms near housings. However, it is difficult to control the acoustic emergence as it rapidly evolves with weather conditions and noise conditions.

Presently, pre-studies are made to establish the restriction strategy that must be set in the wind farm control system (SCADA). They consist in 2 weeks measurement campaigns where the wind turbines are periodically turned off. The difference between the measured ambient levels (with the turbines on) and the residual noise levels (with the turbines off) give an estimate of the acoustical emergence. In order to cope with the variability of those levels, the measures are classified with weather conditions (wind speed, wind direction and periods of the day) and the emergence is considered constant in each class. Yet, there are still strong variations on the system parameters and hence current studies have to consider worst case scenarios. This leads to great economic losses since the production is highly correlated to the noise emission.

For this reason, a finer control of the noise pollution has become essential to optimise the economic gain. To address this, VENATHEC SAS (France) have proposed a new control system called iEAR that is based on real-time acoustic measurement to allow a finer control of the wind turbines. The design of the control algorithm opened a challenge in the fields of audio source separation and stochastic control.

2 Approach

The main issue is that the emergence criterion must remain below a given threshold for each housing around the farm. Acoustical emergence depends both on residual noise (acoustic noise power due to other sources than wind turbines) and on particular noise (noise power due to the wind turbines). This double dependency is difficult to control:

- The residual noise around a housing strongly varies over time, even within a single day. Yet, it is not possible to measure the residual noise directly and it is impossible to explain these variations with a physical model.
- The particular noise depends on the current acoustic emission and on the energy loss due to the acoustic propagation which strongly varies with the weather conditions. Theoretically, they can be both computed easily:
  - The current emission can be calculated from the current operating modes and measured wind speed given the manufacturers' power curves.
  - The propagation energy loss can be simulated using a physical model with ray tracing.

The control of the particular noise level can be handled by a physical model and we chose to use the manufacturers power curves and simulated propagation data stored as look-up tables. However, the measurement and the variability of the residual noise level requires to design a new control system. For that purpose, Venathec and Inria have proposed to use real-time **source separation** and a new **control model**.

Because of the novelty of this field of research, we decided to design first an **instantaneous and deterministic model** based on the approximation usually made for the problem of allocating acoustic operating modes. We tested our algorithm on real-data from 3 different wind farms using campaigns' measures for the acoustic levels, simulations for the propagation data, and the manufacturers curves. The algorithm is to be field tested before the end of the current year (2015).

3 Main body of Abstract

3.1 The instantaneous and deterministic control model

The first control algorithm we designed was based on the following hypothesis:

- We considered no lack of reactivity of the wind turbines.
- We considered no uncertainties on the simulation data.
- For the calculations, we have considered a simplified formulation of the emergence criteria. Indeed, as the acoustic emergence measure is currently bases on on-off cycles, the complete formulation is somehow complex and is based on median values of the ambient and the residual noise over time. However, we decided to develop an instantaneous approach and we used an instantaneous criterion. Nevertheless, we have theoretically and experimentally shown that with special precautions, the complete criteria is *a posteriori* fulfilled.

Figure 1 gives the general operation scheme of the first model

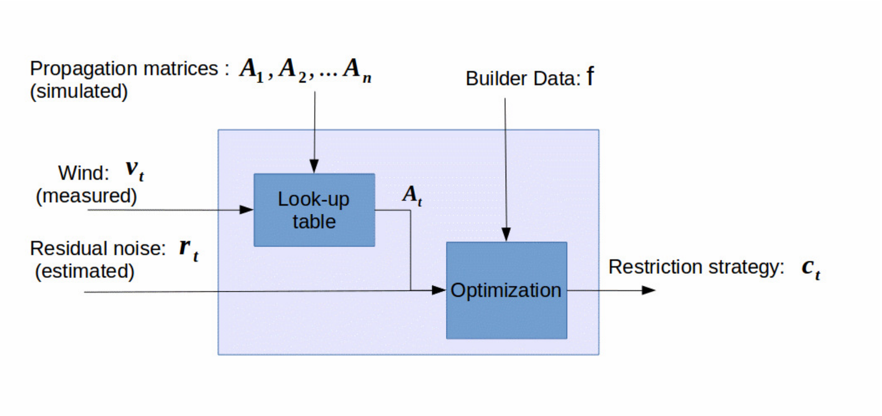

Figure 1: General operation scheme of the instantaneous and deterministic system

The wind speed and the wind direction measured at the turbines hub and the residual power estimated by the source separation system are the input data. From the wind data, the corresponding acoustic power attenuation matrix is retrieved and the optimisation is then computed with the power curves to build the restriction strategy to be applied for the next 10 minutes.

3.2 Optimisation unit

We have shown that the deterministic and instantaneous hypothesis allows us to write the problem as a *nonlinear convex discrete programming problem* or equivalently as a *nonlinear knapsack problem* [3, 5]:

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

We solved the problem with an adapted *branch and bound algorithm* [2]. However, we had to adapt the instantaneous criteria in order to fulfil the complete emergence criteria by comparing the obtained result with the static strategy, which is the current strategy used on wind farms. Figure 2 gives the algorithm used eventually.

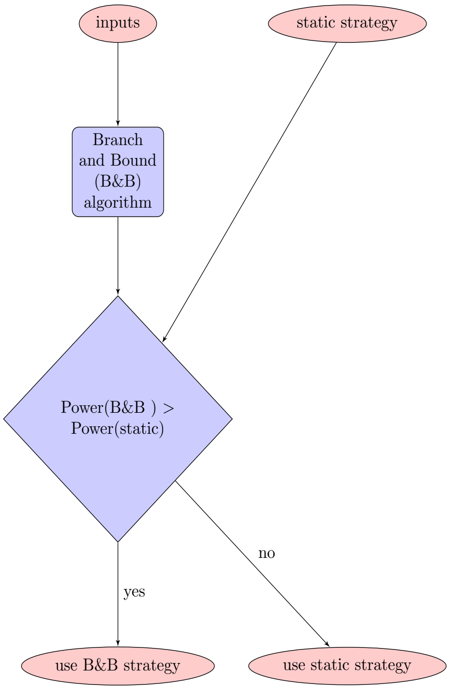

Figure 2: General scheme of the optimisation unit.

3.3 Experiments

We experimentally verified that the branch and bound algorithm yields most of the time the optimal results (98,5% of the 1210 test cases). Then, we simulated the acoustical control with the acoustical data coming from 3 wind farms. The detailed results are given in Figure 3 and 4.

Production loss (%) 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
instantanous control	1.4	30.7	0	53.6	0	0

Figure 3: Production losses compared to full-power operation and static strategy (current acoustic control)

Acoustic excesses (% 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 control	30	31	1	31	0	1

Figure 4: proportion of acoustic excesses over time (in percent of the full duration)

4 Conclusion

On this new issue, we finely analysed the problematic and we have identified the needs. We proposed a simple control method that is both simple to implement and efficient. Though, to refine the optimisation, we can use more general hypothesis:

- Concerning the wind turbines reactivity, our approximation is acceptable since the reactivity to switch from an operating mode to another one is most of the time very small for the wind turbines that will be used for field testing. However, a more general problem can be formulated using short-term wind predictions [4] and dynamic programming [1].
- The particular noise model is to some extent acceptable as the power curves and the propagation models are considered for worst case scenarios. However, recalibration of the acoustic power curves/propagation data and the remaining uncertainties will be considered in further research.

5 Learning objectives

- Introduce the acoustic control problem and present the key topics related.
- Present a first efficient solution to the problem.

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