INTERNSHIP PROPOSAL

Subject: **HANDLING MODEL MISMATCH IN CLOSED-LOOP CONTROL OF WIND FARMS**

Company: **IFP Energies nouvelles**
Supervisor: **Paolino Tona (paolino.tona@ifpen.fr), Digital Science and Technology Division**
Location: **IFPEN Rueil-Malmaison (92) or IFPEN Lyon, Solaize (69)[1]**
Duration: **5 months en 2024**
Compensation: **about 1050 € gross / month**

Description

Wind farm control is a relatively new technology that involves controlling wind turbines collectively in order to optimize total production or their structural health, or any other criterion representing the overall performance of a wind farm. The operating points are thus chosen to reduce wake effects in the "general interest" of the park and not to maximize the individual production of each turbine.

At IFPEN, we are particularly interested in wake steering control, which is achieved by misaligning the wind turbines relative to the prevailing wind, via a modification of the setpoint applied by the turbine yaw control system. In the "open loop" control approach, an optimization is performed offline (i.e., without feedback) on a digital model of the wind farm for all given wind conditions, in order to calculate the yaw misalignment setpoints to be applied to each turbine, which are then stored in maps to be used online based on the estimated wind conditions in the park. A "low fidelity" physical model (a simplified steady-state model) is generally used, which predicts the time-averaged effects of a control policy on energy production and mechanical loads.

To overcome the limitations of open loop wind farm control, where misalignment maps are calculated offline once and for all, another wind farm control methodology, known as "closed loop", is beginning to be studied. It involves using field information and measurements to calculate misalignment setpoints by dynamically adapting to the operating conditions of the farm. One way to implement this type of control is to calibrate an online stationary model like the one previously described (which thus becomes a digital twin of the farm) by estimating some uncertain parameters and launching an optimization with the current wind conditions as input. However, one can expect inaccuracies in the model, given the difficulty of describing the flows in the park in a simple way and the great diversity of spatial and temporal scales. In the presence of a mismatch between the model and the system (plant-model mismatch), which, if the model is structurally incorrect, cannot be corrected by estimating the parameters more adapted to the current conditions, it is not guaranteed that the optimal yaw commands calculated from the model are also optimal for the system (the wind farm).

In this context, it may be interesting to try to characterize the model error and integrate it into the optimization process. This is the idea behind real-time optimization (RTO) by modifier adaptation (MA), initially proposed by researchers from the Ecole Polytechnique de Lausanne [1]. This technique, the most common variants of which are described in [2], involves directly adapting the optimization problem using measurements to allow convergence to the system global optimum. Standard MA adds first-order modifiers to correct the gradient (and constraints) of the surrogate model. More recently, in [3], the use of a Gaussian process (GP) was proposed to correct the model, in order to overcome some limitations of the MA. To complete the description of the context, the MA-GP approach was taken up by L.E. Andersson from the Norwegian University of Science and Technology in a series of articles published in 2020 [4][5][6][7], to be applied to closed-loop wind farm control. The approach seems promising, but it remains to be verified what its real advantages

[1] The site is accessible by public transport (Lyon-Feyzin shuttle then GE2 bus line).

are compared to two-step model-based approaches and model-free approaches (considering that the use of a Gaussian process also allows to completely dispense with a physical model of the wind farm, in a Bayesian optimization context, as proposed in [6]). More specifically, we are asking ourselves:

- How to effectively handle the dynamics induced by low-level yaw control, and especially those due to the propagation of wakes in the wind farm (delays in the effects of a yaw setpoint modification).
- How to ensure that there is enough information to allow the estimation of the hyperparameters of the Gaussian process.

The internship will involve examining these questions in greater depth on the basis of case studies proposed by IFPEN. The simplified physical models will be based on stationary wind farm simulators such as FLORIS or FarmShadow. The approach will be validated using medium-fidelity simulators such as WFSim, FLORIDyn or the dynamic extension of FarmShadow.

The intern will have the opportunity to work in a promising field with a wealth of scientific and technical knowledge.

[1] Marchetti, A. G., Chachuat, B., and Bonvin, D.: *Modifier adaptation methodology for real-time optimization*, Indust. Eng. Chem. Res., 48, 6022–6033, 2009.
[2] Marchetti, A. G., François, G., Faulwasser, T., and Bonvin, D.: *Modifier Adaptation for Real-Time Optimization – Methods and Applications*, Processes, 4, 55, 2016.
[3] de Avila Ferreira, T., Shukla, H. A., Faulwasser, T., Jones, C. N., and Bonvin, D.: *Real-Time optimization of Uncertain Process Systems via Modifier Adaptation and Gaussian Processes*, in: IEEE 2018 European Control Conference (ECC), 12–15 June 2018, Limassol, Cyprus, 465–470, 2018.
[4] Andersson, Leif Erik; Bradford, Eric Christopher; Imsland, Lars (2020): Distributed learning for wind farm optimization with Gaussian processes. In: 2020 American Control Conference (ACC). 2020 American Control Conference (ACC). Denver, CO, USA, 7/1/2020 - 7/3/2020: IEEE, pp. 4058–4064.
[5] Andersson, Leif Erik; Bradford, Eric Christopher; Imsland, Lars (2020): Gaussian processes modifier adaptation with uncertain inputs for distributed learning and optimization of wind farms. In IFAC-PapersOnLine 53 (2), pp. 12626–12631. DOI: 10.1016/j.ifacol.2020.12.1833.
[6] Andersson, Leif Erik; Doekemeijer, Bart; van der Hoek, Daan; van Wingerden, Jan-Willem; Imsland, Lars (2020): Adaptation of Engineering Wake Models using Gaussian Process Regression and High-Fidelity Simulation Data. In J. Phys.: Conf. Ser. 1618 (2), p. 22043. DOI: 10.1088/1742-6596/1618/2/022043.
[7] Andersson, Leif Erik; Imsland, Lars (2020): Real-time optimization of wind farms using modifier adaptation and machine learning. In Wind Energ. Sci. 5 (3), pp. 885–896. DOI: 10.5194/wes-5-885-2020.

Desired profile

- 3rd year engineering student or equivalent, ideally Master 2 in research.
- Very good grounding in automatic control, applied mathematics and data science.
- A good knowledge of mechanics would be a plus.
- The candidate shall be proactive.
- Ability to read scientific publications in English, to understand the state of the art on the subject.

How to apply

To apply, please send your CV and cover letter to the internship supervisor Paolino Tona (paolino.tona@ifpen.fr).