MsC thesis description sheet

Background

Wind farm control refers to the multiobjective optimization of wind power plant operation, balancing power production revenues with downtime and repair maintenance costs while providing ancillary services to the grid and handling possible faults. This involves a complex interdisciplinary interconnection of processes, from farm-level electro-mechanical and flow (atmosphere and wakes) interactions to component-level degradation mechanisms via the aero-hydro-servo elastic response of the individual turbines.

This problem needs a holistic approach, treating each of its aspects with a sufficient level of fidelity. Holistic analytical models relying on linear system theory are available, but their accuracy is questionable for critical tasks such as wake flow modelling and fatigue damage calculation. Machine learning-based surrogate modelling (known also as metamodeling) shows a complementary potential. The concept is based on characterizing input-output relationships from a dataset generated by accurate numerical simulations, to obtain a computationally efficient black-box model meant to be used in lieu of its physics-based parent. By carefully selecting inputs and outputs, control algorithms may then be designed, and their stability proven by relying on the computational efficiency to scrutinize all possible situations (within the limits of the training dataset).

This approach has been successfully used by Dimitrov et al. in their work[1,2,3] (among others), providing a good basis for artificial neural network-based surrogate modelling. However, the focus was set on surrogate models of individual turbines, placed in wake-modified flow. Farm-level simulations and surrogates have not been considered. NREL's FAST.farm is a recently developed mid-fidelity, open-source engineering model able to model the aero-hydro-servo elastic response of an entire wind farm[4]. Its decent computational cost and modelling philosophy makes it suitable for extensive cloud computing for efficient data generation. This enables the use of machine learning to train data-driven models such as artificial neural networks or polynomial chaos expansions, used to synthetically give power production and structural response of individual turbines as function of wind conditions and individual turbine configurations. Using this surrogate in an optimization loop offers a promising approach for the mechanical aspect of wind farm control.

Work description

The aim the MsC thesis is to investigate the potential of surrogate modelling of wind farm dynamics using FAST.farm. This amounts to:

- Learning about surrogate modelling and defining the optimal structure (the underlying maching learning method and its inputs / outputs) for the current application
- Using FAST.farm for massive data generation
- Training and validating the surrogate model
- Demonstrating a proof of concept of surrogate modelling-based wind farm flow control / wake optimization

This problem is complex, and accurate quantitative results are not expected to be achieved within a single MsC thesis. The aim is a proof of concept, where realizability and transferability are prioritized. To this end, simplifications may be thought:

- Standard surrogate modelling methods like artificial neural networks are preferred, the goal not being to make advances in machine learning methods
- The number of parameters (number of turbines, number of turbine configuration and wind condition parameters) may be reduced
- The cost function (balance between power production revenues and repair costs) may be simplified

These simplifications may be lifted if time allows. Regarding transferability, an agreement will be made balancing each party's interests regarding programming philosophy, computing practicalities and dissemination.

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[1] Dimitrov, N. K., Kelly, M. C., Vignaroli, A., & Berg, J. (2018). From wind to loads: wind turbine site-specific load estimation with surrogate models trained on high-fidelity load databases. Wind Energy Science, 3(2), 767-790.
[2] Riva, R., Liew, J. Y., Friis-Møller, M., Dimitrov, N., Barlas, E., Réthoré, P-E., & Beržonskis, A. (2020). Wind farm layout optimization with load constraints using surrogate modelling. *Journal of Physics: Conference Series*
[3] Schröder, L., Dimitrov, N. K., & Sørensen, J. A. (2020). Uncertainty propagation and sensitivity analysis of an artificial neural network used as wind turbine load surrogate model. *Journal of Physics: Conference Series*
[4] Jonkman, Jason M., et al. "Development of FAST. Farm: a new multi-physics engineering tool for wind-farm design and analysis." 35th Wind Energy Symposium. 2017.