POLITECNICO DI BARI

Dipartimento Meccanica Matematica Management

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Research project

Name and Surname: Pietro De Palma

Title: Off-shore wind farm control using multi-agent deep reinforcement learning

Description:

The project focuses on a key aspect of wind energy, namely, the optimization of the power extraction from wind farms. To meet the EU Green Deal targets, it is essential to improve the efficiency and optimize the power of off-shore wind farms, minimizing land and sea use. Today, a great effort is dedicated to design larger turbines, with greater rotor diameters and hub heights, which operate in regions of the atmospheric boundary layer with higher velocity and significant velocity variations.
However, stand-alone wind turbines are uncommon. They are usually arranged in farms, whose optimization involves the joint interactions among turbines due to wake effects. Wakes have a negative impact on the farm performance since they represent a defect of energy in the wind flow and they bring high velocity fluctuations increasing fatigue effect on downstream turbines. Wakes may cause a reduction in the farm power production of 12% in offshore wind farms. Therefore, trade-offs between power generation and fatigue loads can be determined in the design of an efficient wind farm at the single-turbine level and at the farm-level optimization.
These issues pose challenges in: 1) determining the optimal layout of the farm; 2) predicting the performance of large off-shore wind farms; 3) controlling the power generation and the load response of the turbines as a function of the wind conditions and farm layout. Understanding these phenomena will enhance farm performance, reliability, and durability of off-shore wind farms.
The project aims to analyze the turbine interactions in a wind farm by using high-fidelity computations based on large eddy simulations (LES). LES of wind farms will be conducted in conjunction with the actuator disk model or the actuator line model for the turbine rotor, depending on the number of turbines composing the farm.
The study employs UTD-WF, a computational code previously applied in wind power research [1]. This code simulates various atmospheric boundary layers, accounting for turbulence and Coriolis-induced Ekman spirals, enabling adjustments to turbine operating conditions. The governing equations use second-order centered finite differences on a staggered Cartesian grid, with a third-order Runge-Kutta scheme for nonlinear terms and a Crank-Nicolson scheme for linear terms. UTD-WF has been used by the research groups of Politecnico di Bari and University of Texas at Dallas for aeroelastic studies on NREL 5MW and 15MW models [2], yaw control effects on wind farm power production [3] and reduced-order modeling through Proper Orthogonal Decomposition and Dynamic Mode Decomposition [4, 5].
Initially operational on CPU machines (e.g., Lonestar6 at TACC), the code has been adapted for GPU machines, showing significant computational speed increases, especially on grids with 2.7 billion cells. This enables large-scale simulations without physical time constraints, allowing wind farm-scale structural analyses.
Usually, single-turbine PID controllers use the measured wind information and the turbine state at a previous time step to adjust the settings of the turbine for maximizing the power production. The effects of neighboring turbines are implicitly contained in the measured data. However, the optimal operating state is not the result of a truly joint optimization, which has the potential of providing an improved optimal solution in terms of power and loads. Therefore, the aim of this project is to globally control the pitch and yaw of all turbines in the farm to optimize power and loads, while capturing turbine wake interactions.
The problem of joint-control of wind farm is very challenging for several reasons involving the complexity of the flow field, the non-linear interactions among the turbines and the computational cost for taking decisions in a short time of the order of some seconds.
Model-based predictive control with semi-centralized approaches have been proven to be successful only with a small number of turbines.
The present project aims at developing a reinforcement learning (RL) [6] based approach. In RL, an agent learns to achieve an objective by interacting with the environment through the reward feedback. In the present case, the environment is represented by the high-fidelity LES simulations considering both energy and fatigue loads in the reward definition. The project will analyse different RL approaches, such as a multi-agent RL setting, in which individual agents are coupled together with shared global rewards.

References:

[1] C. Santoni et al., "Development of a high fidelity cfd code for wind farm control," DOI: 10.1109/ACC.2015.7170980.

[2] C. Bernardi et al., “The effect of the tower’s modeling on the aero-elastic response of the NREL 5 MW wind turbine," DOI: 10.1088/1742-6596/2505/1/012037.
[3] F. Bernardoni et al., "Identification of wind turbine clusters for effective real time yaw control optimization," Journal of Renewable and Sustainable Energy 13.4 (2021).
[4] F. Manganelli et al., "The effect of Coriolis force on the coherent structures in the wake of a 5MW wind turbine," DOI: https://doi.org/10.1016/j.ecmx.2024.100830.
[5] F. Manganelli et al., "Assessing the Effect of Coriolis Acceleration on the Coherent Structures in the Wake of a Wind Turbine Using Dynamic Mode Decomposition," DOI: https://doi.org/10.1115/1.4067120.
[6] Richard S. Sutton, Andrew G. Barto, Reinforcement Learning: an Introduction, MIT press, 2018.

Candidates should provide detailed CV

Contacts

Pietro De Palma: pietro.depalma@poliba.it