Development of analysis and simulation tools for certification and validation of wind turbine control systems

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Wind energy is a rapidly growing field all over the world, with the year 2020 being a historic year in terms of the global growth in installed wind power capacity. In the upcoming decade, wind turbines need to be installed at even a faster rate to mitigate the worst impacts of climate change and help in achieving global zero-carbon electricity production goals. In Lebanon, a public-private partnership was signed, pre-economic-crisis in 2018, to construct the country's first wind farms in Akkar, North Lebanon, with the objective of alleviating the country's chronic power shortage. For wind turbines to be competitive within the global energy market, the cost of generating wind power should be economically competitive with conventional power production methods. For this purpose, high-performance and reliable wind turbines are required. The area of control systems has significantly contributed to the reduction of the cost of wind-generated electricity by enabling the maximization of power generation and the minimization of mechanical loads on the turbine's components. As a by-product of the extended wind turbine lifetime, the carbon footprint of wind turbines is further minimized by reducing the need for manufacturing more wind turbine blades.

In this proposal, we first look at the base unit of a wind farm, the wind turbine, from a control-theoretic point of view to address the several challenges brought about by large-scale wind turbines. Namely, wind turbines are highly nonlinear dynamical systems, whose modeling spans various disciplines, and are subject to varying wind conditions, and so are challenging to control. The control objectives are the maximization of the generated power and the minimization of the loads on the turbine components. As the size of wind turbines grows, considerations on load reduction become even more critical. This motivates the development of robust control strategies that ensure robust and satisfactory performance of wind turbines for any operating condition. Additionally, for their integration into the electric grid at a large scale, wind turbines need to able to meet the demand from the grid despite time variations in wind speed.

This work proposes the development of a comprehensive model-based framework for the analysis and certification of wind turbine control systems using tools from robust control theory, particularly, linear parameter varying systems and the theory of integral quadratic constraints. The proposed framework is modular and provides a systematic and rigorous tool for designing, testing, and certifying that a controller is safe for implementation on a real wind turbine. The framework also allows for comparing the robustness and the performance of different controllers with respect to different outputs as well as comparing the same controller's performance across varying wind speeds. Thus, the proposed framework offers mathematical rigorous tools that complement and systematize the extensive simulations typically performed on high-fidelity wind turbine models for controller testing and validation. One novelty of the framework is that it allows for the incorporation of a turbulent wind model into the analysis, thereby allowing for an improved characterization of the system’s performance to match the observations obtained via simulations and implementation.

One advantage of the proposed framework is that it formulates the robustness analyses as semidefinite programs to be solved using efficient numerical solvers, which speeds up the iterative control design and analysis processes. Another advantage is that the framework allows for obtaining performance upper bounds that are of a worst-case type and cover all simulations. That is, it defines a guaranteed operating envelope that cannot be violated during wind turbine operation. Since real-life implementation of controllers on wind turbines is expensive and risky, this framework helps in reducing costs by discarding controllers that cannot be certified as safe.

In addition to the above, we propose to optimize wind turbine performance using data-driven control approaches and machine learning tools specialized for control purposes. We will also look at wind farm optimization using tools from networked dynamical systems and distributed optimization. Generally, the proposed work is as a required precursor for future studies that will deal with the design with distributed control approaches for wind farms.

Finally, the proposed project involves a collaboration with international world-renowned scholars in the field of wind turbine control systems, as well as a reaching-out component to relevant stakeholders in the Lebanese wind turbines and energy sector for impact maximization.