Paper ID APEN-MIT-2022_xxx
Applied Energy Symposium: MIT A+B
July 5-8, 2022 • Cambridge, USA

Nested Control Co-design of a Spar Buoy Horizontal-axis Floating Offshore Wind Turbine

Saeid Bayat
Department of Industrial and Enterprise Systems Engineering
University of Illinois at Urbana-Champaign
Urbana, IL, USA
bayat2@illinois.edu

Yong Hoon Lee
Department of Industrial and Enterprise Systems Engineering
University of Illinois at Urbana-Champaign
Urbana, IL, USA
ylee196@illinois.edu

James T. Allison
Department of Industrial and Enterprise Systems Engineering
University of Illinois at Urbana-Champaign
Urbana, IL, USA
jtalliso@illinois.edu

Abstract—Floating Offshore Wind Turbine (FOWT) system design involves analysis of several coupled disciplinary domains, including aeroelasticity, multi-body structural dynamics, hydrodynamics, and controls. In conventional design processes, making physical (plant) and control design decisions are treated as two separate problems; generally, control system design is performed after plant design is completed. However, this sequential design approach cannot fully exploit the synergies that exist between plant and control design decisions. Sequential design may produce significantly suboptimal designs, especially when there is a strong coupling between plant and control design decisions. Control Co-Design (CCD) is a holistic design approach that accounts fully for plant-control design coupling by optimizing these decisions simultaneously. CCD is especially advantageous for system design problems with complex interactions between physics disciplines, which is the case for FOWT systems. When combined with Open-Loop Optimal Control (OLOC), CCD provides insightful design references that can reveal new active dynamic behaviors, generate novel high-performance plant design, and provide targets and other actionable insights that inform practical implementation of plant and control design with feedback control. This study demonstrates a nested CCD approach based on OLOC for a simplified Reduced-Order Model (ROM) that simulates dynamic behaviors of a spar buoy-based horizontal-axis FOWT system. The dynamic ROM developed for this study consists of important governing physics terms, including hydrodynamic forcing, aerodynamics, and mooring dynamics. This model solves dynamic responses of three platform degrees of freedom and a rotor rotational degree of freedom for time-domain blade pitch and generator torque control inputs created by the optimizer. This ROM is helpful for optimization studies due to its computational efficiency, but is still sufficiently rich in capturing important multidisciplinary physics couplings and plant-control design couplings associated with a horizontal-axis spar buoy FOWT system. The nested CCD formulation utilizes the Covariant Matrix Adaptation Evolution Strategy (CMA-ES) in the outer loop problem to explore plant design changes, and within the inner-loop OLOC problem the Legendre-Gauss-Lobatto pseudospectral collocation method is implemented and solved using the IPOPT solver. The CCD result shows an improvement in the objective function, annual energy production (AEP), compared to the baseline design by more than eleven percent. Optimization studies at this fidelity level can provide system design engineers with insights into design directions that leverage design coupling to improve performance. These studies also provide a template for future more detailed turbine CCD optimization studies that utilize higher fidelity models and design representations.

Keywords—floating offshore wind turbine, spar buoy platform, control co-design, open-loop optimal control, reduced-order modeling