Master Thesis

Theory and programming

Advanced control of large scale fixed-bottom offshore wind turbines for support structure load mitigation

Conditions:

Duration:	6 Months
Requirements:	Strong ability in MATLAB programming Strong knowledge in Control Theory
Language:	English
Target groups:	Master students

Content:

The rising demand for energy as well as environmental concerns from fossil-based energy sources has increased interest in renewable energy. Wind and solar are the fastest growing renewable energy sources. To meet the growing demand for wind energy, there has been a continued growth in the physical dimensions and power rating of Wind Turbines (WTs). With increasing size, WTs are becoming heavier and flexible, leading to increased inertial, gyroscopic, and gravitational loading of its components during operation. A vast majority of large WTs are designed for offshore wind projects because of less constraints related to manufacturing size and acoustic noise concerns, and limited interference with land-use. Offshore wind speeds are also steadier and faster. Offshore WTs include fixed-bottom and floating types. Although a floating platform is economic in deep water (above 50 m) installations, it adds extra complexity due to additional degrees of freedom. Based on the incident wave and wind thrust, the platform can exhibit extra motion including surge, sway, heave translations as well as roll, pitch, yaw rotations. Damping of platform motions is crucial. On the other hand, fixed-bottom offshore WTs suffer from aerodynamic and hydrodynamic loading produced by wind and sea conditions. Tower fore-aft and side-side motions are responsible for fatigue loading of the support structure, which is amplified by scouring effect at the seabed. Wind-wave misalignment increases the complexity of loading [1].

Modern WTs are instrumented with several sensors and actuators. This enables implementation of several objectives including, load mitigation, power optimization and structural health monitoring. Classical PID controllers are becoming increasingly less effective in meeting the requirements of these Multi-Input Multi-Output (MIMO) systems. Therefore, modern control strategies have been deployed for load mitigation of support structures in fixed-bottom offshore WTs albeit with collateral effects like high loading in other components and reduced rotor speed/power regulation performance. MIMO controllers can be utilized to solve such multi-objective problems that require a balance between conflicting goals. One such controller is Disturbance Accommodating Controller (DAC), which incorporates disturbance models in the design.

Along with evolution in WTs, state-of-the art Reference Wind Turbines (RWTs) reflecting the current and future trends in wind energy have been developed to study new technologies and advance the next generation of WTs [2]. These RWTs have been widely used for testing modern control techniques.

Supervisor:	Edwin Kipchirchir, SRS	Dirk Söffker, SRS
Office:	MB 361b	MB 341
Telefon:	01788363029	0203 / 379-3024
E-Mail:	edwin.kipchirchir@uni-due.de	soeffker@uni-due.de

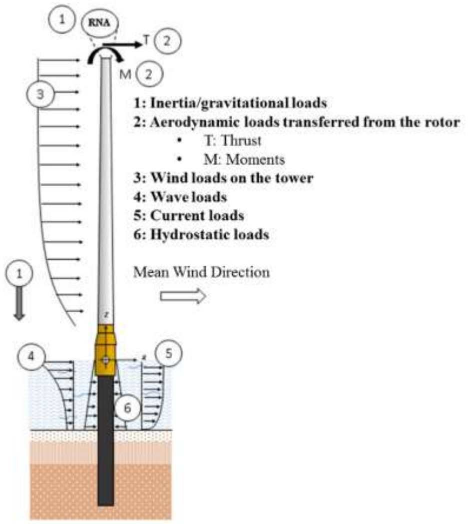

Figure 1 Loads on a support structure of a fixed-bottom offshore wind turbine [3].

The goal of this thesis is to design and implement a DAC Controller to mitigate support structure loads in the NREL 5 MW offshore RWT [4]. A gain-scheduled PI controller is to be designed as a baseline controller for evaluating the performance improvement of the developed control strategy.

The detailed goals of the thesis are as follows:

- Design a gain-scheduled PI controller to serve as a baseline controller for rotor speed regulation in the above-rated wind speed region without considering loading mitigation.
- Design DAC controller for mitigating support structure loading under different wind-wave conditions.
- Evaluate the performance of the DAC controller against the baseline controller by performing simulations using coupled loading influences of step/stochastic wind, regular/irregular waves.

The steps related to this work can be summarized as:

1) Design a gain-scheduled PI controller for speed regulation in the above-rated wind speed region.
2) Implement the PI controller in MATLAB/Simulink.
3) Simulate the 5 MW RWT with the PI controller in the loop using different load cases of step/stochastic wind and regular/irregular waves.
4) Generate an appropriate linearized (reduced order) state-space model of the nonlinear (full order) model of the 5 MW RWT to capture important dynamics.
5) Design a DAC controller using the obtained linear time-invariant model for reducing structural loading in the support structure.
6) Implement the closed loop system in MATLAB/Simulink.
7) Simulate the closed loop system under different wind-wave conditions.
8) Compare the results obtained using different controllers and draw conclusions.
9) Complete a detailed documentation and present the research results.

In case good results are generated, the candidate will be invited to be a co-author of a publication to be submitted to a reputable conference/journal.

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E-Mail:	edwin.kipchirchir@uni-due.de	soeffker@uni-due.de

[1] B. Shrestha and K. Martin, “Adaptation of Controller Concepts for Support Structure Load Mitigation of Offshore Wind Turbines,” in *13th Deep Sea Offshore Wind R&D Conference, EERA DeepWind’2016*, 2016, vol. 94, no. January, pp. 241–248.
[2] J. Rinker, E. Gaertner, F. Zahle, N. Abbas, H. Bredmose, and G. Barter, “Comparison of loads from HAWC2 and OpenFAST for the IEA Wind 15 MW Reference Wind Turbine,” in *J. Phys.: Conf. Ser. 1618 052052*, 2020.
[3] T. Gentils, L. Wang, and A. Kolios, “Integrated structural optimisation of offshore wind turbine support structures based on finite element analysis and genetic algorithm,” *Appl. Energy*, vol. 199, pp. 187–204, 2017.
[4] J. Jonkman *et al.*, “Definition of a 5-MW Reference Wind Turbine for Offshore System Development,” Golden, Colorado, 2009.

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