Design of offshore windfarms WP6.3 - D63.3 Offshore wind turbine control - DTU Orbit (18/11/2019)

Design of offshore windfarms WP6.3 - D63.3 Offshore wind turbine control

This deliverable presents control algorithms for offshore wind turbines that can reduce the cost of energy by mitigating load reductions on the tower and support structure as well as unwanted swings and motions of the tower and nacelle. In turn, this can lead to reduced initial investments and thus to reduced levelized cost of energy. As a reference wind turbine, the 10 MW DTU reference wind turbine is selected, and adjusted to two support structures. A monopile is used to represent a bottom-mounted wind turbine, and a triple spar floating platform is used for simulations with floating wind turbines. For both cases, baseline controllers were adapted and tuned, with an option of using additional control loops for load reduction, such as individual pitch control, and control algorithms for reduction of tower loads based on collective blade pitching, generator torque, and individual blade pitching. Besides showing load reductions achievable by the proposed control concepts, the deliverable also discusses their possible industrial exploitation, showing that mostly software updates are required with no or only modest updates to the standard sensor equipment or actuators of modern multi-megawatt wind turbines. Load reduction with different control algorithms is analysed in aeroelastic simulations in GH Bladed under various atmospheric and sea states, which are obtained by lumping over 20 years of measurement data. It is concluded that some control algorithms achieve higher load reduction in certain operating conditions, meaning that – by identifying such conditions and using an adaptive activation strategy – actuator activity can be reduced without significantly reducing load reduction. As an example, when activating individual pitch controller only in selected atmospheric and sea states, one can reduce the actuator duty cycle over 25 % by losing only 15 % of the maximal achievable tower load reduction. Additionally, a significant impact on the support structure lifetime, and therefore on the levelized cost of energy, is shown as a function of the control effort, i.e. of the actuator duty cycle. It is shown that avoiding additional pitch activity in 50 % of the cases can already lead to the threefold increase of the support structure lifetime, indicating that further reductions in material are possible. To achieve even further load reduction, a series of different control loops for load reduction is replaced with a single optimal state space controller, LQR, which takes care of the wind turbine power control, reduction of blade loads, nacelle motion, and tower loads. This enables a better synchronisation among different control objectives, and more coordinated control actions towards achieving control objectives. The controller and the state estimator are designed based on a linearized mathematical model in the d-q coordinate system, and tested in aeroelastic simulations with turbulent wind conditions and irregular waves. It is shown that the more coordinated control actions can achieve further load reductions, with up to 5 % damage equivalent load (DEL) reduction of the fore-aft tower bending moment, and up to 1 % DEL reduction of the side-to-side tower bending moment compared to the baseline controller extended with standard control algorithms for load reduction. Additionally, the proposed control concept achieves slight reductions in the actuator activity (up to 1.5 %) and the standard deviation of the generated power (up to 13 %). The deliverable also presents a control strategy based on the predictive observer-based feedforward control, which can effectively reduce wind turbine loads in extreme operating conditions, and help in avoiding shutdown procedures. Such an approach can lead to reductions in the blade root flapwise bending moment of more than 30 %, which has an important impact on the loads envelope and the blade design. Furthermore, it is shown that the floating platform pitch tilt moment can be reduced by 15 %, the mooring anchor tension (1 m) can be reduced 13 %, and the fairlead around 8 %. Other loads are reduced in the range of 5 %, such as tower base fore-aft bending moment, and the mooring fairlead and anchor tensions at 2 m and 3 m. These results are obtained because the proposed controller anticipates risky situations, and either avoids a shutdown procedure, which additionally reduces the wind turbine downtime and thus increases the energy production, or it initiates a shutdown in a better condition and thus reduces ultimate loads. The obtained results show a possible reduction in blade weight and cost of up to 27 %, and a reduction of levelized cost of energy of up to 1.18 %, which is besides in material savings also driven by a slight increase of annual energy production. The unwanted swings and motions of floating wind turbines can cause the generator speed control loop using conventional blade pitch controller to become unstable at above rated wind speeds. To minimise such swings and motions, the blade pitch demand, produced by the basic controller, is augmented by an adaptive adjustment in response to tower fictitious forces at frequencies below tower natural frequency. Tower fictitious forces are apparent forces acting on the nacelle mass, when the WT is mounted on a non-stiff structure, which produces fore-aft and side-to-side unwanted motions described using a non-inertial reference frame. The developed control task is independent of the platform and wave dynamics and the strongly WT aerodynamic gain can be counteracted by global gain-scheduling. Besides guaranteeing stability, the control algorithm is extended to alleviate tower fatigue loads and reduce power fluctuations on the drive-train components by reducing blade pitching activity in the vicinity of the tower fore-aft natural frequency. It is shown that such a control concept enables the use of lighter floating platforms, thus also leading to reductions in the initial investment costs and levelized cost of energy, without the need to redesign standard control algorithms. Finally, the deliverable discusses requirements on the wind turbine systems from the grid operators, and defines design cases which can be used to test the compatibility of control systems with the grid requirements.

General information
Publication status: Published
Organisations: Integration & Planning, Department of Wind Energy, Wind turbine loads & control, National Renewable Energy Center, ForWind, Centre of Renewable Energy Resources and Saving, SINTEF, Consiglio Nazionale delle Ricerche, University of Strathclyde
Number of pages: 133
Publication date: 2018

Publication information
Original language: English

Bibliographical note
IRP/WIND 609795. This is an internal report and therefore not available in full text. Please contact author's or director of author's department for further information.

Research output: Book/Report › Report – Annual report year: 2018 › Research