Open-loop analysis of aeroelastic frequency response of NREL 5.0 MW wind turbine

Sønderby, Ivan Bergquist; Hansen, Morten Hartvig

Published in:
Proceedings of EWEA 2012 - European Wind Energy Conference & Exhibition

Publication date:
2012

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Ivan Bergquist Sønderby(1) (F) (P) Morten Hartvig Hansen(1)

(1) DTU Wind Energy, Roskilde,

Introduction

Approach

Main body of abstract

The purpose of this work is to analyze the frequency response of a modern wind turbine from collective pitch demands and generator control actions to changes in rotor speed in open-loop.

Predictions of the frequency responses from actuators to sensors are necessary for proper wind turbine control design. The controller must be designed based on a model that correctly predicts the response of the wind turbine to meet the objectives of the controller. Proper design of a wind turbine controller can reduce power variations and fatigue and extreme loads on components and thereby increase their lifetime.

Control design for wind turbines is often done using design models of low order. Bossanyi [3] has suggested appropriate complexity of models to be used for control design of a pitch-regulated, variable-speed wind turbine. When operating below the rated wind speed with generator torque control, it is suggested to use a model that contains at least the rotational dynamics of the drivetrain including the first torsional mode. For above rated operation using collective pitch control it is suggested to model at least the rotor rotation, the torsional drivetrain dynamics, tower for-aft vibration and the dynamics of the pitch actuator. It is suggested to model aerodynamics using local gradients of the aerodynamic torque and thrust of the rotor.

In this work, the open-loop frequency response functions from generator torque and collective pitch angle demand to rotor speed variations are estimated based on the recent linear model developed at Risø-DTU. The model is a geometrical nonlinear finite beam element model coupled with an unsteady Blade Element Momentum model of aerodynamic loads including effects of dynamic stall. The model is currently being extended with the effects of dynamic inflow.

In normal operation for selected wind speeds in the range 5-25 m/s. It is shown that the frequency responses are predicted well by the linear model when comparing with results obtained from time simulations using the nonlinear model and simulations model with small control inputs. Errors on the predicted amplitudes are below 2 % for small amplitude excitation.
The frequency response predicted by the linear model is found by applying a Laplace transformation on the linear system of equations followed by a matrix inversion. The frequency response predicted by time simulations using the nonlinear model is obtained by cutting out a controller once a stationary steady state is reached and then initiating harmonic actuator inputs with generator torque and collective pitch angle demands. A Fourier transformation is made on the time signals and the frequency response at the input frequency is extracted, whereby nonlinear effects and remaining transients are neglected.

Figure 1 and 2 shows a comparison of the frequency response functions from variations in generator torque and collective pitch angle demands to rotor speed variations as predicted by the linear and nonlinear model of HAWC2 simulations. The error on low-frequency pitch excitation can be explained by the effects of dynamic inflow. There is good agreement between the linear and nonlinear model for small amplitude excitation. Dynamic inflow will be included in the results from the linear model before paper submission.

The frequency response from generator torque to rotor speed variations is dominated by the effect of the linear model. The frequency response is done for normal operation at 8 and 20 m/s. Figure 3 shows the errors on the amplitudes. The linear model does not include a model of the dynamic inflow, whereas dynamic inflow is included in the model of HAWC2 simulations. The error on low-frequency pitch excitation can be explained by the effects of dynamic inflow. There is good agreement between the linear and nonlinear model for small amplitude excitation. Dynamic inflow will be included in the results from the linear model before paper submission.

Figure 1 and 2 shows the open-loop frequency response from collective pitch angle demand to rotor speed variations. In these results it is assumed that the response of the actual pitch angle to a pitch angle demand input is the response of a second order filter with very high frequency. It is essential that the data-scayt_word="linearization" data-scaytid="143">linearization</data-scayt_word> is performed around a nonlinearly deflected state of the blades for correct prediction of the frequency response from pitch angle demand to rotor speed. In operation at 8 m/s the aerodynamic thrust is larger than at 20 m/s, resulting in larger nonlinear amplification at the aeroelastic frequency of 1.7 Hz that couples torsional mode with 1<sup>st</sup> drivetrain mode and rotor rotating in a solid-body rotation. At very low frequencies there is a clear difference in the frequency response for operation at 8 and 20 m/s, which is due to lower aerodynamic damping at 8 m/s of this solid-body rotation mode. The response at low-frequency generator torque excitation is governed by the high rotational inertia of the entire system of the blades for correct prediction of the frequency response from pitch angle demand to rotor speed variations as predicted by the linear and nonlinear model of HAWC2 simulations. The error on low-frequency pitch excitation can be explained by the effects of dynamic inflow. There is good agreement between the linear and nonlinear model for small amplitude excitation. Dynamic inflow will be included in the results from the linear model before paper submission.

The frequency response from generator torque to rotor speed variations is governed by the high rotational inertia of the entire system of the blades for correct prediction of the frequency response from pitch angle demand to rotor speed variations. In these results it is assumed that the response of the actual pitch angle to a pitch angle demand input is the response of a second order filter with very high frequency. It is essential that the data-scayt_word="linearization" data-scaytid="143">linearization</data-scayt_word> is performed around a nonlinearly deflected state of the blades for correct prediction of the frequency response from pitch angle demand to rotor speed. In operation at 8 m/s the aerodynamic thrust is larger than at 20 m/s, resulting in larger nonlinear amplification at the aeroelastic frequency of 1.7 Hz that couples torsional mode with 1<sup>st</sup> drivetrain mode and rotor rotating in a solid-body rotation. At very low frequencies there is a clear difference in the frequency response for operation at 8 and 20 m/s, which is due to lower aerodynamic damping at 8 m/s of this solid-body rotation mode. The response at low-frequency generator torque excitation is governed by the high rotational inertia of the entire system of the blades for correct prediction of the frequency response from pitch angle demand to rotor speed variations as predicted by the linear and nonlinear model of HAWC2 simulations. The error on low-frequency pitch excitation can be explained by the effects of dynamic inflow. There is good agreement between the linear and nonlinear model for small amplitude excitation. Dynamic inflow will be included in the results from the linear model before paper submission.

The open-loop frequency response from collective pitch angle demand to rotor speed variations has been found from collective pitch angle demand and generator torque control signals to changes in rotor speed for the NREL 5.0 MW wind turbine in normal operation at 8 and 20 m/s. The frequency responses are predicted with the linear model of the new code HAWCStab2 and validated with the nonlinear model of HAWC2 [2]. The linear model can be used for design of model-based wind turbine controllers after order reduction has been applied. To correctly predict the frequency response from pitch angle demand to rotor speed, it is found to be important that linearization is performed around a nonlinearly deflected blade. The frequency responses are seen to be mainly influenced by the solid-body rotor rotation mode. The frequency response from generator torque to rotor speed variations is influenced greatly by a zero located at 0.6 Hz which exist due to a
coupling of the solid-body rotor rotation mode and the 1<sup>st</sup> drivetrain mode. Control of the rotor speed with generator torque close to 0.6 Hz will be difficult due to low amplification level.

The final paper will include a discussion of the aeroelastic frequency responses from collective pitch angle demands and generator torque to rotor speed variations for normal operation at 5-25 m/s. The effects of dynamic inflow on the frequency responses will also be discussed.

Figure 1: Open-loop transfer function from generator torque to rotor speed variations. Comparison between aeroelastic response predicted using the nonlinear HAWC2 model and the linear HAWCStab2 model.

Figure 2: Open-loop transfer function from collective pitch angle demand to rotor speed variations. Comparison between aeroelastic response predicted using the nonlinear HAWC2 model and the linear HAWCStab2 model.

Figure 3: Error of amplitudes of rotor speed variations predicted from HAWC2 simulations and the linear HAWCStab2 model in percentage of rated speed.

Conclusion