Dynamic Analysis of Floating Wind Turbines Subjected to deterministic Wind Gust

Xuwen Wang
xuwenw@stud.ntnu.no

NTNU
Norwegian University of Science and Technology

Problem

In some excessive conditions, rapid increase of wind speed occurs and damage to the wind turbine structure is possible, as for example during tropical storms. The values of wind speed and turbulence parameters are intended to represent many different sites but do not give a precise representation of any specific site. Therefore, an extreme wind profile is necessary. By studying extreme dynamic response in terms of two unspecified parameters, peak wind speed and duration of gust in a simple wind turbine model built with Matlab, extreme wind profile will be found in return period of 50 years.

Basic Concept

This work focuses on the time domain response under extreme deterministic wind gust, in a return period of 50 years, for which simulations are carried out in order to assess the turbine's performance and build the database utilizing softwares SIMA, FAST and Matlab.

Based on equations of motion of platform, a simplified dynamic wind turbine model inspired by the DTU 10-MW Reference Wind Turbine was built in Matlab to study extreme response subjected to deterministic gusts defined in *DNV-OS-J103: Design of Floating Wind Turbine Structures*. Simple model includes generator torque and blade pitch control system converted from NREL 5-MW source code in FAST written in Fortran. Extreme loads on mooring system can be assessed by surge and pitch offsets of platform in output.

Models

Equations of Motion The floating wind turbine can be regarded as a rigid body when considering the motion responses. In my case, there are three degrees of freedom. For a symmetric rigid body: spar, the dynamic motion and load of six degree of freedom can be reduced to two coupled motions: surge and pitch in one set of equation of motions. Generator torque control works as the third degree of freedom.

$$\left(\begin{bmatrix} m & -m*z_G & 0 \\ -m*z_G & I_{wl} & 0 \\ 0 & 0 & I_{Rot} \end{bmatrix} + \begin{bmatrix} -\rho AD & \rho AD*\overline{BG} & 0 \\ \rho AD*\overline{BG} & \rho A(\frac{D^3}{12}+D*\overline{BG}^2) & 0 \\ 0 & 0 & 0 \end{bmatrix} \right) \begin{bmatrix} \ddot{\eta}_1 \\ \ddot{\eta}_5 \\ \ddot{\eta}_{Rot} \end{bmatrix}$$

$$+ \begin{bmatrix} 2\zeta_s\varpi_{ns}m_s & 0 & 0 \\ 0 & 2\zeta_p\varpi_{np}m_p & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \dot{\eta}_1 \\ \dot{\eta}_5 \\ \dot{\eta}_{Rot} \end{bmatrix} + \left(\begin{bmatrix} 0 & 0 & 0 \\ 0 & \nabla\overline{GM_L} & 0 \\ 0 & 0 & 0 \end{bmatrix} + \begin{bmatrix} k & kh & 0 \\ kh & kh^2 & 0 \\ 0 & 0 & 0 \end{bmatrix} \right) \begin{bmatrix} \eta_1 \\ \eta_5 \\ \eta_{Rot} \end{bmatrix}$$

$$= \begin{bmatrix} F_1 \\ F_5 \\ \Delta Q \end{bmatrix} \quad F_1 = \frac{1}{2}\rho A C_T V^2, \quad Q_{aero} = \frac{1}{2}\rho\pi R^3 C_q V^2, \quad \Delta Q = Q_{aero} - Q_{gen} = I_{rot}\dot{\Omega}$$

Blade Pitch Control Adopting PI control method inspired by NREL 5-MW wind turbine, the blade pitch angle was associated with rotor speed:

$$\theta = K_P \triangle\Omega + K_I \int_0^t \triangle\Omega dt + K_D \triangle\dot{\Omega},$$

$$K_P(\theta) = \frac{2I_{Drivetrain}\Omega_0 \xi_\varphi \omega_{\varphi n}}{-\frac{\partial P}{\partial\theta}(\theta=0)} GK(\theta)$$

$$K_I(\theta) = \frac{2I_{Drivetrain}\Omega_0 \omega_{\varphi n}}{-\frac{\partial P}{\partial\theta}(\theta=0)} GK(\theta),$$
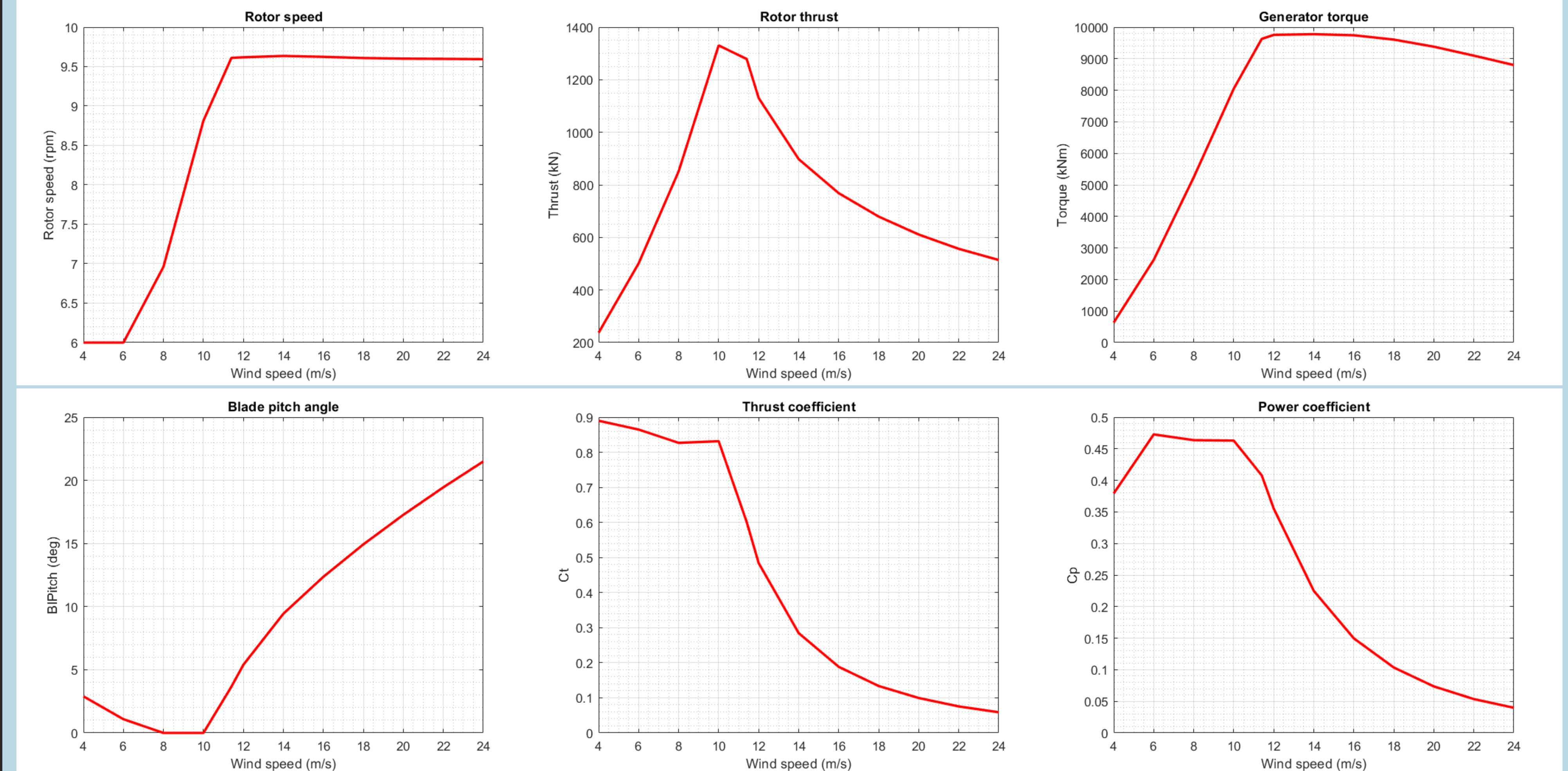
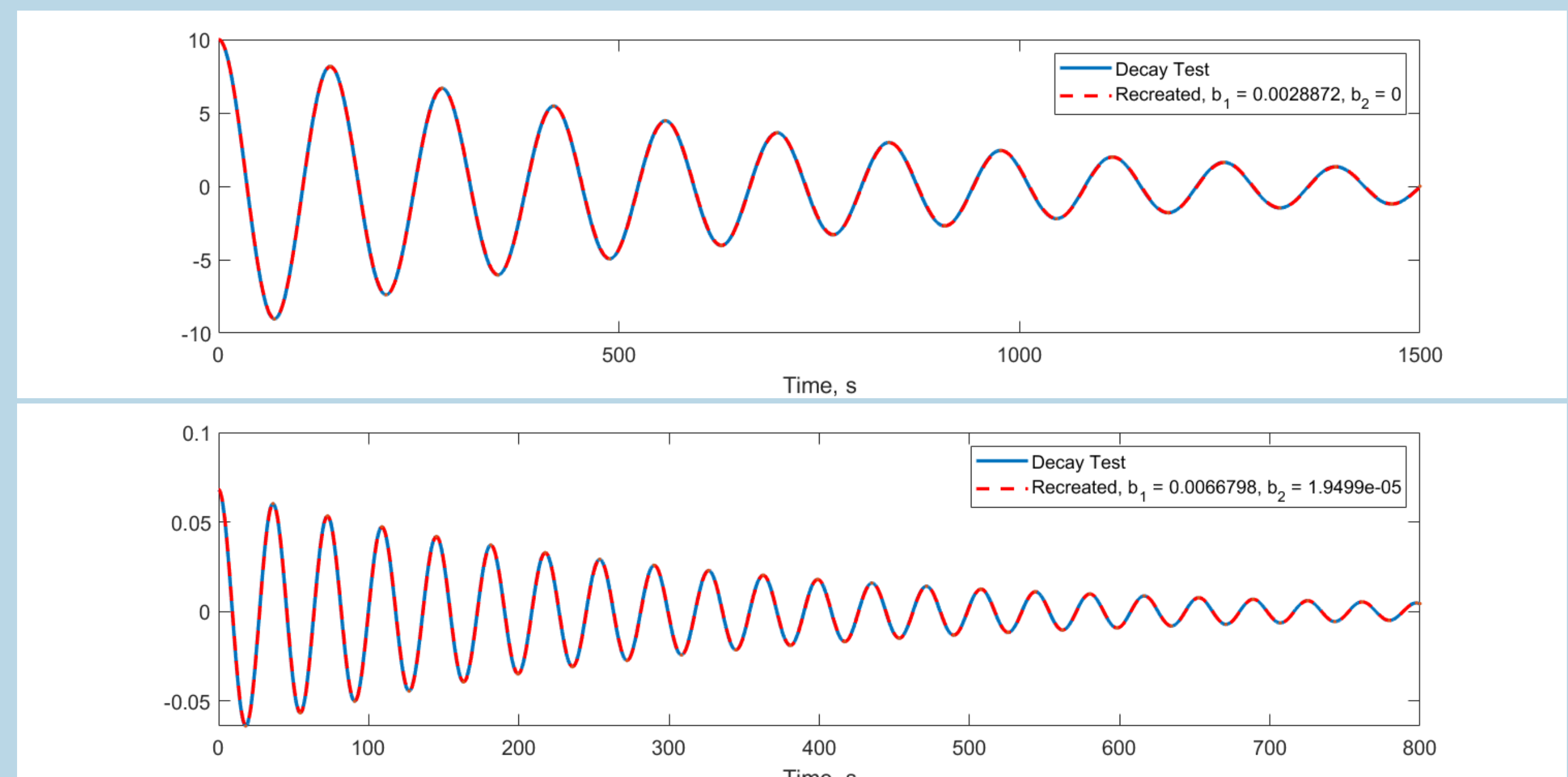$$GK(\theta) = \frac{1}{1+\frac{\theta}{\theta_k}}.$$

References

[1] O. M. Faltinsen: *Sea Loads on Ships and Offshore Structures*, Cambridge University Press 1, (1990)

[2] Wenfei Xue: *Design, numerical modelling and analysis of a spar floater supporting the DTU 10MW wind turbine*, Master thesis, NTNU (2016)

[3] J.M. Jonkman : *Dynamics Modeling and Loads Analysis of an Offshore Floating Wind Turbine* , No. NREL/TP-500-41958. United States, (2007).

Verification Tests

Constant Wind Tests A constant wind test is one of the basic tests for verifying performance of wind turbines, including a controller, from which we can get rotor speed, thrust, torque, power and blade pitch curves, with varying wind speeds at hub height. It also will be one of databases in wind turbine modeling of Matlab.
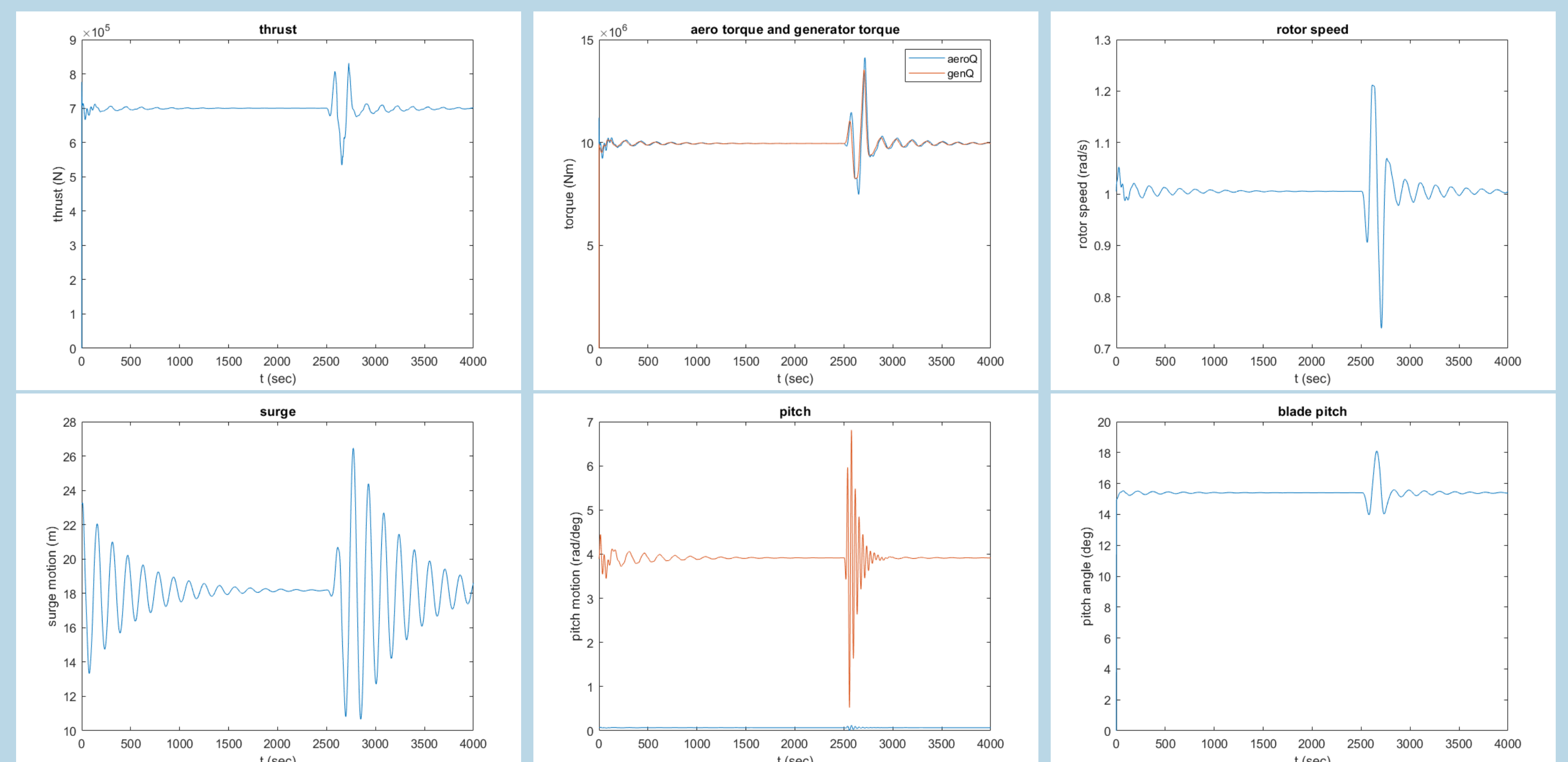

Decay Tests Decay tests of surge and pitch are performed to verify the accuracy of a wind turbine model both in SIMA and Matlab, aiming to obtain natural period of each platform motion and corresponding damping ratio.

Extreme Wind Response

Working on extreme operational gust defined in $DNV-OS-J101$, the peak value of wind speed will be specified under given mean wind speed. However, the duration of gust is uncertain. Taking the case of dynamic response under regular wave as reference, gusts with duration close to natural period of platform motions are assumed to cause more severe fluctuation of the structure. Examples shown below are in case of mean wind speed equal to 18m/s, time series of surge and pitch motions of the platform, gust happens at 2500th second:

At each mean wind speed, fluctuation of surge and pitch motion changes with different duration of gust, when the crest of gust has the same duration with natural period of surge and pitch, which are 139 s and 37 s, respectively, the extreme response shows up.