A Note on the Modification of Controller before Putting the DTU 10MW RWT onto a Floating Platform

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This note applies to the DTU controller with the DTU 10MW reference wind turbine (See Ref [1] for details of the turbine and controller). The following work is based on the coupled dynamic simulation of the DTU 10MW RWT mounted on a semi-submersible platform by the SIMO-RIFLEX-AeroDyn code. But the modifications of the controller parameters may also apply to other situations.

All modifications are performed within the ControlInput.txt file.

Mean Wind Speed

“The controller as defined by DTU uses a low-pass filtered measurement of the wind speed in order to set the minimum pitch of the controller. RIFLEX doesn't give any wind speed measurement to the java controller, so I included this "mean wind speed" input that determines where you are in the minimum pitch table. I was hoping at some point to either 1) change RIFELX so that it sends the hub-height wind speed to the controller or 2) read that value from the RIFLEX output file (this would work, but would be a pretty slow way to do it). Unfortunately, that is not a code modification I ever really had the time to implement.

If you are interested in wind speeds greater than 6 m/s, your options are:

1) Set the mean wind speed to be something between 7 and 10 m/s -> this will give you minimum pitch close to 0. It won't be exactly the behavior according to DTU, but it should give predictable and stable behavior.

2) Modify the java code and implement the wind speed measurement from the riflex output file/low pass filter. (Another option would be to have the controller read the wind input, but I think that would actually be more work).

For very low wind speeds, I think that you should actually set the "mean wind speed" input correctly (unlike the NREL 5MW, this turbine is designed for the blades to be pitched for low wind speeds).”

----Erin Bachynski

Gain Constants

Mounting the DTU 10MW RWT onto a floating platform may experience some pitch resonant motion, as shown in Figure 1.

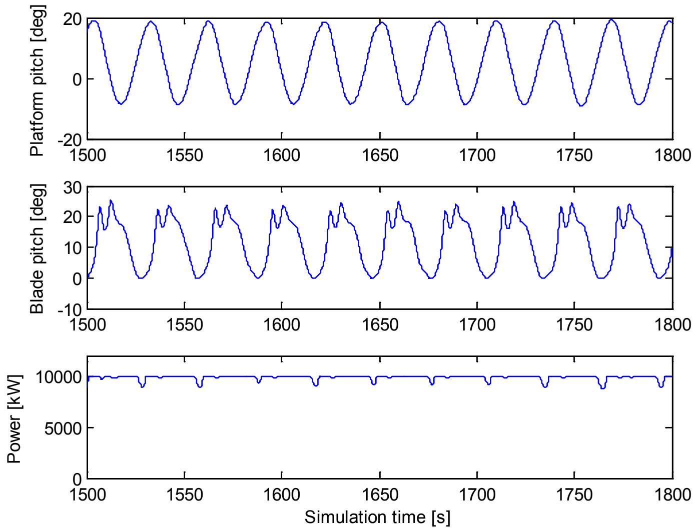

Figure 1. Example of the pitch resonant motion caused by blade pitch controller for a floating DTU 10MW RWT, with 18m/s constant wind speed, JONSWAP irregular wave with 4.1m significant wave height and 10.5s wave peak period

The resonant pitch motion of the floater is caused by negative damping from the blade pitch controller. This phenomenon is also reported by Nielsen[2] in the analysis of Hywind concept, Jonkman[3] in the analysis of ITI Energy barge concept and Roddier[4] in the analysis of WindFloat concept.

The DTU 10MW RWT controller is based on classical proportional-integral (PI) theory[1]. According Jonkman, such blade pitch control system follows the following equation of motion[5]:

$$\underbrace{\left[I_{Drivetrain}+\frac{1}{\Omega_0}\left(-\frac{\partial P}{\partial \theta}\right)N_{Gear}K_D\right]}_{M_\phi}\ddot{\varphi}+\underbrace{\left[\frac{1}{\Omega_0}\left(-\frac{\partial P}{\partial \theta}\right)N_{Gear}K_P-\frac{P_0}{\Omega_0^2}\right]}_{C_\phi}\dot{\varphi}+\underbrace{\left[\frac{1}{\Omega_0}\left(-\frac{\partial P}{\partial \theta}\right)N_{Gear}K_I\right]}_{K_\phi}\varphi=0 \quad (1)$$

where $I_{Drivetrain}$ is the drivetrain inertia cast to the low speed shaft, N_{Gear} is the high-speed to low-speed gearbox ratio, Ω_0 is the rated low-speed shaft rotational speed, P_0 is the rated mechanical power, $\partial P/\partial\theta$ is the sensitivity of aerodynamic power to the rotor collective blade pitch angle, K_P, K_I and K_D is the blade pitch controller proportional, integral and derivative gain respectively, $\dot{\varphi}=\Delta\Omega$ is the rotor speed error.

It is seen that the rotor speed error will response as a 1 dof dynamic system with natural frequency $\omega_{\varphi n}$, and damping ratio ζ_φ equal to:

$$\omega_{\varphi n}=2\pi f_{\varphi n}=\sqrt{\frac{K_\varphi}{M_\varphi}},\ \ and\ \ \zeta_\varphi=\frac{C_\varphi}{2M_\varphi\omega_{\varphi n}} \quad (2)$$

In the design of blade pitch controller[6], the PI gains can be determined by neglecting the derivative gain and negative damping term in Equation (1)

$$K_P = \frac{2I_{Drivetrain}\Omega_0\zeta_\varphi\omega_{\varphi n}}{N_{Gear}\left(-\frac{\partial P}{\partial \theta}\right)}, \quad and \quad K_I = \frac{I_{Drivetrain}\Omega_0\omega_{\varphi n}^2}{N_{Gear}\left(-\frac{\partial P}{\partial \theta}\right)} \tag{3}$$

Currently, the land-based DTU 10MW RWT uses blade pitch controller natural frequency of 0.06Hz (0.38rad/s) and a damping ratio of 0.7[1]. This natural frequency is above the natural frequency of the floater pitch motion, 0.04Hz (0.24rad/s). According to Larsen[7], the smallest controller response natural frequency must be lower than the smallest critical support structure natural frequency to ensure that the support structure motions of an offshore floating wind turbine with active pitch-to-feather control remain positively damped. Therefore, reducing the controller response natural frequency to 0.03Hz (0.19rad/s) will ensure that it is lower than the floater pitch natural frequency and lower than the excitation frequency of most sea states.

Therefore, the PI gains are reduced according to Equation (3) to achieve the desired controller response natural frequency while keeping the damping ratio unchanged. Table 1 shows an example of modifications of the PI gains. Figure 1 confirms that the modification successfully avoids the pitch resonance.

Table 1. Example of modification of the PI gains of the blade pitch controller

	Default value for the land-based DTU 10MW RWT	Target value for the floating DTU 10MW RWT
Blade pitch controller natural frequency, $f_{\varphi n}$ [Hz]	0.06	0.03
Proportional gain, K_P	0.524485	0.262243
Integral gain, K_I	0.141233	0.035308

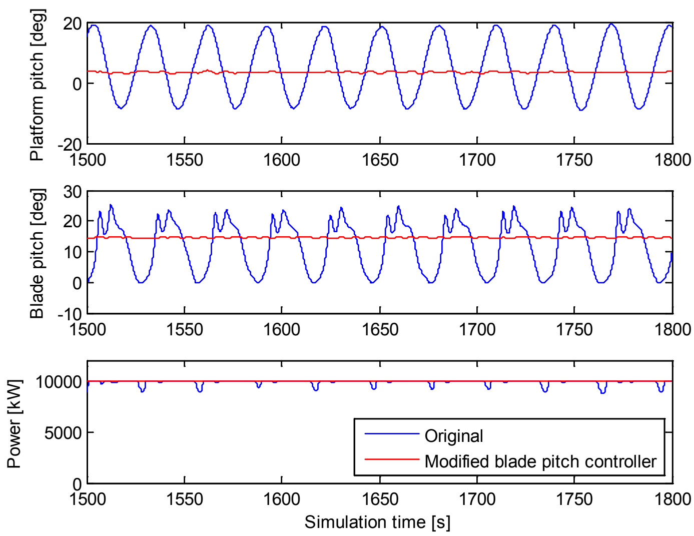

Figure 2. Comparison of response with the original and the modified blade pitch controllers

Reference

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5. Jonkman, J., et al., *Definition of a 5-MW Reference Wind Turbine for Offshore System Development*. 2009, National Renewable Energy Laboratory.
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