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Reduction of dynamic response and wind turbine loading for floating offshore wind turbine system using feed forward control

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SUMMARY

This study investigates dynamic responses and wind turbine loads of a floating offshore wind turbine system using LiDAR-assisted feed forward control. For nacelle acceleration feedback combined with LiDAR-assisted feedforward collective pitch control (NAF+FFCPC), dynamic analysis under operating conditions reveals that the optimal feedforward gain at rated wind speed is 0.6. Compared with NAF alone, NAF+FFCPC reduces the cumulative blade pitch motion and platform pitch motion without reducing mean power production or increasing the maximum fore-aft tower base moment. LiDAR-assisted feedforward independent pitch control (NAF+FFIPC) combined with NAF suppresses the blade root out-of-plane moment caused by wind, waves, and rotor rotation, reducing the tower base load and platform motion compared to NAF+FFCPC. Compared to PI control, the blade root moment, tower base load and floater pitch motion are significantly reduced by 27%, 39%, and 63%, respectively, and the cumulative blade pitch displacement is also reduced by 27%.

Keywords: *LiDAR-assisted feedforward control, independent pitch control, cumulative blade pitch motion*

1. INTRODUCTION

To reduce the cost of floating offshore wind power, advanced control techniques are required to reduce platform motion and wind turbine loads. For spar-type floating offshore wind turbines (FOWTs), Honma et al. (2024) demonstrated that nacelle-acceleration feedback (NAF) control reduced platform motion and tower loads. Yamaguchi et al. (2020) showed that combining NAF with LiDAR-assisted feedforward collective pitch control (NAF+FFCPC) for a fixed-bottom turbine can reduce tower base loads, but did not address blade pitch motion. Kakuya et al. (2021) applied NAF+FFCPC to an advanced spar-type FOWT in the full-scale demonstration project (Fukushima FORWARD) and reported that NAF alone increased the cumulative blade pitch motion due to control-loop interference between conventional PI control and NAF control, whereas adding FF control reduces the cumulative blade pitch motion due to the absence of a feedback loop in the FF path. Kakuya et al. (2021) also showed that FF gain affects loads and system response but did not systematically investigate this gain and often selected fixed, conservative values.

Furthermore, as wind turbines become larger, blade loads are expected to increase due to spatial nonuniformity of wind speed caused by wind shear and turbulence. Burton et al. (2021) presented LiDAR-assisted feedforward independent pitch control (FFIPC), which calculates different blade pitch angles for each blade, as an alternative to collective pitch control (CPC), which uses the same blade pitch angle for all blades. Russell et al. (2024) demonstrated the platform motion and blade load reduction effects of combination of NAF and FFIPC (NAF+FFIPC) for a semi-submersible FOWT, but its applicability to spar-type FOWTs has not been evaluated.

In this study, LiDAR-assisted feedforward control is applied to a spar-type FOWT. The optimal FF gain of NAF+FFCPC is systematically evaluated through dynamic analysis of the cumulative blade pitch motion, tower base load, and power output. The effects of NAF+FFIPC on the platform motion and turbine load of a spar-type FOWT are quantitatively evaluated.

2. METHODOLOGY

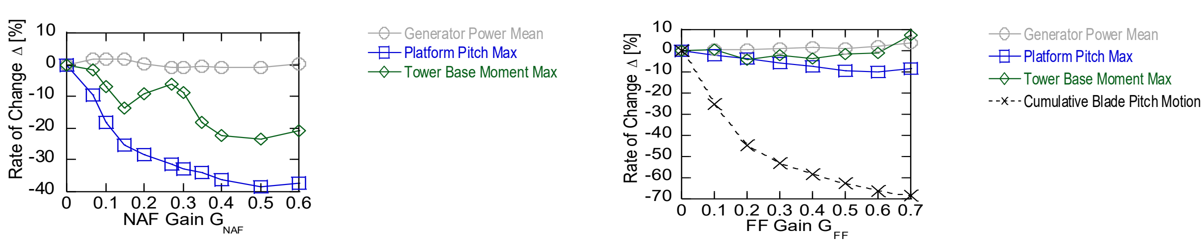
A coupled model of the OC3 Hywind spar-type floating platform (Jonkman, 2010) and a 5MW wind turbine (Jonkman, et al., 2009) is applied, which is widely used as a major reference floating wind turbine design model. Dynamic analysis is performed using the aero-hydro-servo-elastic simulation tool of OpenFAST v4.0.0 (2024) and verified with the reported values (Jonkman and Musial, 2010). The control algorithm is implemented using Simulink (2025). Baseline PI control is employed in all cases, and FF gains at the rated wind speed are optimized by adding NAF and FFCPC following Kakuya et al. (2021). Following Bossanyi (2003) and Russell et al. (2024), FFIPC is applied to the conventional CPC, and NAF+FFIPC is compared with PI alone and NAF+FFCPC. In the FF algorithm, floater motion is considered to calculate wind speed, following Wakui et al. (2022).

To evaluate the optimal FF control gains and the performance of NAF+FFIPC, dynamic analyses are conducted under turbulent conditions with a mean wind speed 14 m/s (Class C) and irregular wave conditions with a significant wave height of 2.05 m. The main response quantities are power output, platform pitch motion, tower base fore-aft moment, and blade pitch angle. For NAF+FFCPC, the FF control uses measured upstream wind speed as input to modify the PI+NAF collective pitch command. For NAF+FFIPC, an additional blade-wise pitch command is generated for each blade based on LiDAR-measured upstream wind speed, blade azimuth angle, and rotor speed, scaled by the FFIPC gain, and superimposed on the collective NAF+FFCPC pitch demand.

3. RESULTS

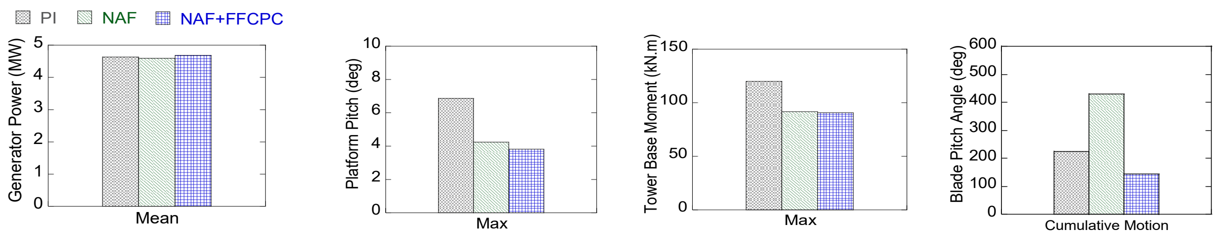
3.1. LiDAR-Assisted Feedforward Collective Pitch Control

To obtain the optimal FF control gain (G_{FF}) for NAF+FFCPC, the NAF control gain (G_{NAF}) is first evaluated. Figure 1(a) shows the evaluated rate of change for various G_{NAF} relative to $G_{NAF} = 0$. The maximum platform pitch motion and tower base moment are minimized at $G_{NAF} = 0.5$. A similar evaluation is conducted for G_{FF}, and the cumulative blade pitch motion is minimized at $G_{FF} = 0.6$, shown in Figure 1(b). Figure 2 shows the dynamic analysis results using these optimal gains. With NAF+FFCPC, the cumulative blade pitch motion is reduced by 67%, from 430° to 144°, compared to NAF control alone, without reducing the mean power output or increasing the maximum tower base moment. Furthermore, the platform pitch motion is reduced by 10%.



(a) NAF gain, G_{NAF} (b) FF gain, G_{FF}

Figure 1: Control gain effects on platform pitch motion, tower base moment, and cumulative blade pitch motion



(a) Mean power output

(b) Maximum platform pitch

(c) Maximum fore-aft tower base moment

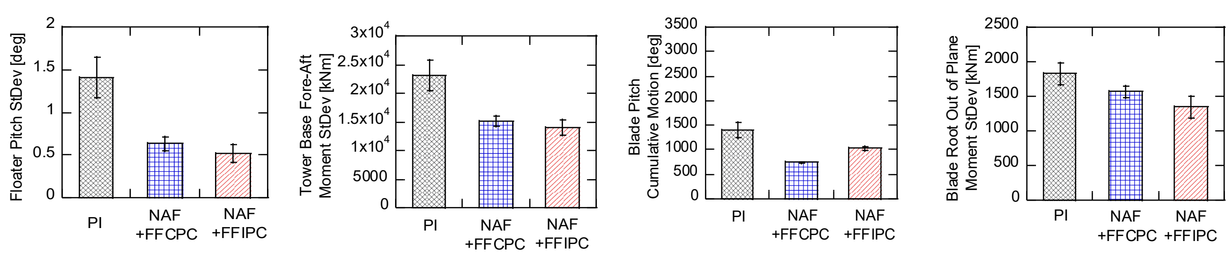
(d) Cumulative blade pitch motion

Figure 2: Comparison of predicted statistics for PI control, NAF, and NAF+FFCPC

3.2. Feedforward Independent Pitch Control

Figures 3 and 4 show the predicted statistics and power density spectra of platform motion and wind turbine load when PI control, NAF+FFCPC, and NAF+FFIPC are applied. As shown in Figure 4(d), NAF+FFIPC suppresses fluctuations in the low-frequency region dominated by wind turbulence, the dominant wave period (around 0.1 Hz), and the rotor rotation frequency 1P (0.2 Hz), reducing the standard deviation by 14%. This reduction in blade loads also reduces the standard deviations of the tower base moment and platform pitch motion by 7% and 18%, respectively, as shown in Figures 3(a) and (b). NAF+FFIPC is more effective at reducing the tower base moment and platform pitch motion than NAF+FFCPC.

As shown in Figure 4(c), applying NAF+FFIPC increases fluctuations in the blade pitch angle at high frequencies above 0.2 Hz, resulting in a larger cumulative blade pitch motion than NAF+FFCPC, as shown in Figure 3(c). This is due to the additional control action to counteract the loads on each individual blade. However, NAF+FFIPC still reduces the cumulative blade pitch motion by 27% compared to PI control alone, confirming the effectiveness of NAF+FFIPC for spar-type FOWTs. Compared to PI control, NAF+FFIPC reduces blade root moment, tower base moment, and floater pitch motion by 27%, 39%, and 64%.



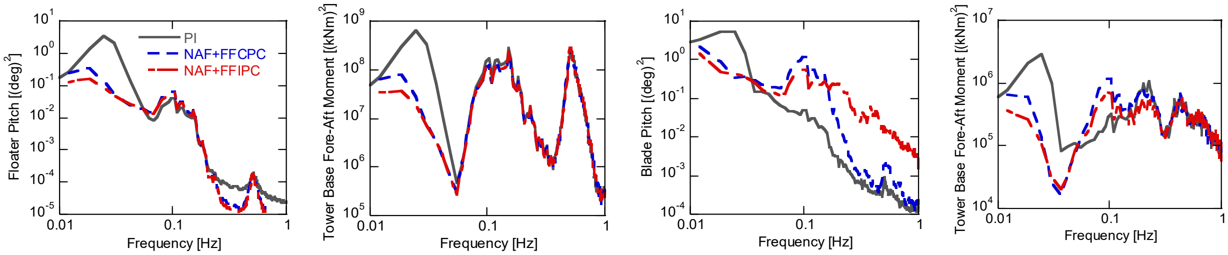
(a) Platform pitch standard deviation

(b) Fore-aft tower base moment standard deviation

(c) Cumulative blade pitch motion

(d) Blade root out-of-plane moment standard deviation

Figure 3: Comparison of predicted motions and loads using PI control, NAF+FFCPC, and NAF+FFIPC



(a) Platform pitch | (b) Fore-aft tower base moment | (c) Blade pitch angle | (d) Blade root out-of-plane moment

Figure 4: Power density spectra of predicted motion and load using PI control, NAF+FFCPC, and NAF+FFIPC

4. CONCLUSION

In this study, dynamic analysis is conducted to investigate the optimal feedforward gain and to evaluate the effectiveness of independent pitch control. The following conclusions are obtained:

1) For NAF+FFCPC, the optimal feedforward control gain at rated wind speed is evaluated to be 0.6. Compared to NAF control alone, NAF+FFCPC reduces cumulative blade pitch motion by 67% and platform pitch motion by 10%, without reducing the mean power output or increasing maximum fore-aft tower base moment.
2) NAF+FFIPC suppresses the blade root out-of-plane moment caused by wind, waves, and rotor rotation. The blade root moment, tower base load and floater pitch motion are significantly reduced by 27%, 39%, and 63% and the cumulative blade pitch displacement is also reduced by 27%, compared to standard PI control.

REFERENCES

Bossanyi, E.A., 2003. Individual blade pitch control for load reduction. Wind Energy, 6(2), 119-128

Burton, T., Sharpe, D., Jenkins, N., Bossanyi, E., Graham, M., 2021. Wind Energy Handbook, 3rd. ed. Wiley

Honma, K., Kikuchi, Y., Ishihara, T., 2024. Study on the reduction of platform motion and wind turbine loads in a spar-type floating offshore wind turbine system through wind turbine control, 79th Annual Academic Conference at the National Meeting in 2024, Japan Society of Civil Engineers. (In Japanese)

Jonkman, J., Butterfield, S., Musial, W., Scott, G., 2009. Definition of a 5-MW reference wind turbine for offshore system development

Jonkman, J., 2010. Definition of the floating system for Phase IV of OC3

Jonkman, J., Musial, W., 2010. Offshore code comparison collaboration (OC3) for IEA Task23 offshore wind technology and deployment, Technical Report, NREL/TP-5000-48191

Kakuya, H., Yoshida, S., Sugino, J., Ishihara, T., 2021. A study on a feedforward control using the nacelle wind speed for downwind-type floating offshore wind turbines. Journal of Wind Energy, 45(2) (In Japanese)

Simulink. 2025, MathWorks, https://www.mathworks.com/products/simulink.html

OpenFAST v4.0.0, 2024,National Renewable Energy Laboratory, https://github.com/OpenFAST/openfast

Russell, A.J., Collu, M., McDonald, A.S., Thies, P.R., Keane, A., Quayle, A.R., 2024. LIDAR-assisted feedforward individual pitch control of a 15 MW floating offshore wind turbine, Wind Energy, 27(4), 341-362

Yamaguchi, A., Yousefi, I., Ishihara, T., 2020. Reduction in the fluctuating load on wind turbines by using a combined nacelle acceleration feedback and Lidar-based feedforward control, Energies 2020, 13(17,), 4558

Wakui, T., Tanaka, K., Yokoyama, R., 2022. Reduction in platform motion and dynamic loads of a floating offshore wind turbine-generator system by feedforward control using wind speed preview, Mechanical Engineering Journal, 9(4), 22-00066