FBsowento One for reliable control of floating offshore wind turbines

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Abstract

The objective of this paper is to evaluate the design and performance of sowento's reliable *FBsowento One*, a feedback controller for Floating Offshore Wind Turbines (FOWTs). FOWTs enable the harvesting of wind energy in deep water locations, unlocking vast renewable energy potential. A controller is required for operating the turbine. It adjusts the generator torque and the blade pitch angle for an optimal operation. However, designing a reliable controller remains a significant challenge for floater designers, as ill-tuned controllers commonly have a large risk of destabilizing the entire system. This paper introduces sowento's controller tuning approach, which guarantees system stability and minimal structural and mooring/cable loads, while achieving high-performance operation. The results highlight its robustness and adaptability across various FOWT designs, making it a critical advancement for the industry. The controller is intended to be used in pre-Front-End Engineering Design (FEED) and FEED stages of FOWT projects, before a wind turbine designer is selected. FBsowento One will be shared with turbine designers without royalties. In addition to the FBsowento One controller, the *FBsowento Next* provides an additional load reduction for low-frequency mooring and structural loads through an advanced multivariable, optimal controller scheme.

Introduction

Floating Offshore Wind Turbines (FOWTs) represent a transformative solution to harnessing wind energy at deep-water locations, where fixed-bottom structures are impractical. By unlocking access to stronger and more consistent wind resources, FOWTs hold significant promise for advancing global renewable energy goals. However, the complexity of these systems presents unique engineering challenges, one of which is designing a feedback controller that can manage the dynamic interactions between the turbine, platform, and changes in environmental conditions, such as wind and waves.

A feedback controller is a fundamental requirement for operating a FOWT, regulating the generator torque and blade pitch angle. In the "partial-load range", the controller ensures an optimal power production. Above rated wind speeds, the controller maintains rated power by pitching the blades in order to avoid overloading. Without a well-designed feedback controller, FOWTs cannot operate stably and efficiently (Larsen et al., 2007). An ill-tuned controller poses significant risks, including degraded performance, excessive structural loads, and even system instability.

This paper presents sowento's latest design of the FBsowento One feedback controller, which has been specifically designed to address these challenges. By leveraging advanced but standardized and partly automated tuning methodologies and over 10 years of wind-turbine control expertise, this controller ensures guaranteed stability, while delivering high-performance operation. The following sections provide a comprehensive evaluation of its design principles, tuning approach, and performance metrics.

Method

To design the collective blade pitch controller for above-rated wind speeds, the SLOW model (Lemmer et al., 2018) is used to obtain a high-quality linear state-space model of the FOWT at each operating point. A Proportional Integral (PI) controller structure with proportional gain K_p, integral gain T_I and floating platform feedback gain K_{float} is selected. Based on the linear model, linear Key Performance Indicators (KPIs) can be assessed for each controller using:

1. Bandwidth: Maximum frequency with tracking of the reference rotor speed
2. Stability margin: Absolute distance to -1 in root locus w.r.t. rotor speed tracking
3. Platform pitch damping: Damping ratio from the dominant pole of platform pitch state
4. Control-wave amplification: Sensitivity to waves w.r.t. the open loop model

By employing the well-established SLOW model, which is widely recognized in research, we obtain the most accurate measures for reliability and performance. A visualization of the KPIs, demonstrated in Figure 1, allows deep understanding of the performance and reliability. The controller for below-rated wind speeds is a standard optimal quadratic generator torque controller. Switching between below- and above rated control is implemented using set-point-fading (Schlipf, 2019).

A FBsowento One controller is designed for the IEA15MW UMaine VolturnUS-S reference turbine (Allen et al., 2020). It is compared against the reference ROSCO controller by using Design Load Case (DLC) 1.2 simulations in the non-linear SLOW model, for the environmental conditions with aligned wind and waves, given in Table 1 in the appendix. The Damage Equivalent Load (DELS) are computed using rainflow counting with Woehler exponent $m = 3$ and reference number of cycles $n_{ref} = 5 \cdot 10^7$. The rotor speed overshoot is computed with respect to the rated value. The statistics are life-time weighted based on the probability of occurrence.

Results

Using an automated tuning procedure, the FBsowento One improves overall performance with realistic turbine loads using less blade pitch action, as demonstrated in figure 2. In addition to improving performance w.r.t. the reference turbine controller, it comes with a full tuning service, and structural integrity report and can be customized to other specific requirements. It can be tuned in 1 to 2 weeks when all the model parameters are provided. The controller is designed for use during the pre-FEED and FEED phases of FOWT projects, prior to selecting a wind turbine designer. We recommend incorporating the controller early in the design process to ensure the best performance and system compliance.

Conclusions

The *FBsowento One* feedback controller demonstrates significant advancements in the reliable operation of Floating Offshore Wind Turbines (FOWTs). The controller achieves guaranteed stability, reduced blade pitch action, and improved overall performance compared to the reference controller by leveraging the SLOW software, accurate linear Key Performance Indicators (KPIs) and an automated tuning procedure. The FBsowento One provides additional value through its comprehensive tuning service, structural integrity reports, and customization options.

FBsowento One enables floater, mooring, and cable designers to refine their systems before moving into the detailed design phase of a project. It provides them with a well-calibrated, industry-standard controller tailored to their specific design, allowing for component optimization without requiring a detailed simulation model of the proprietary wind turbine and its controller. The state-of-the-art controller technology can be easily adopted by Original Equipment Manufacturers (OEMs). It can also be parameterized so that floater designers can optimise their designs even before an OEM is selected. This state-of-the-art controller technology delivers realistic load limits and blade pitch efficiency, promoting the development of reliable, high-performing FOWTs and expanding renewable energy in deep-water locations.

Figure 1: Linear KPIs as a function of proportional gain and integral time constant

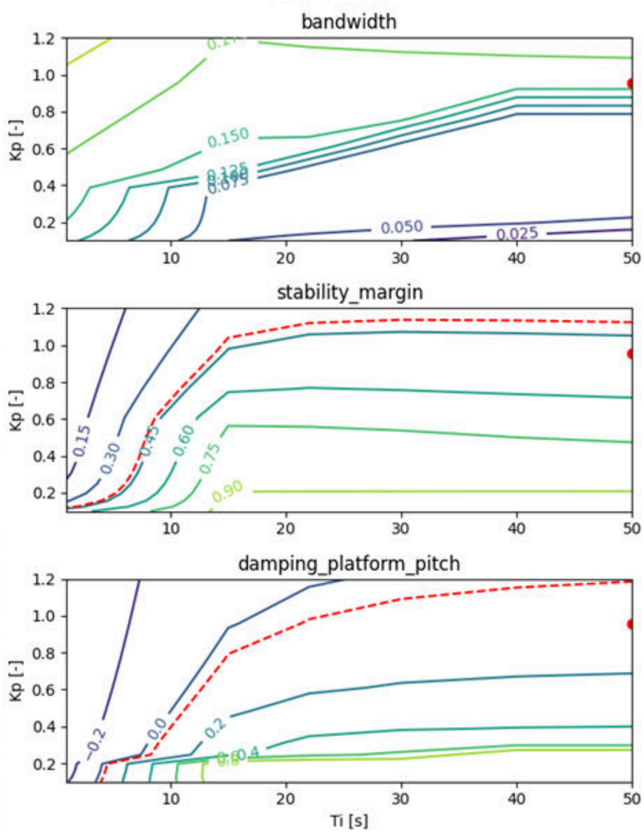
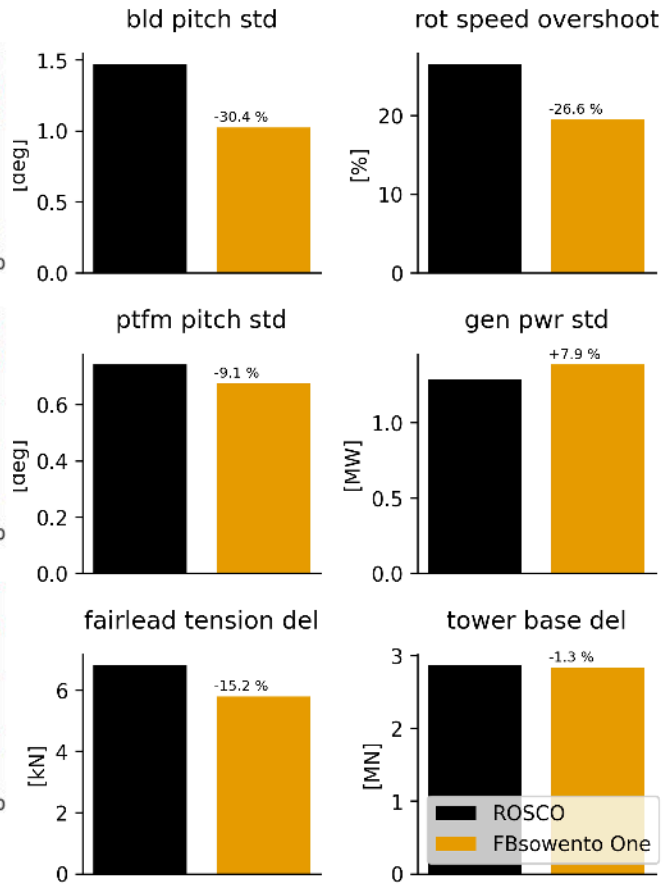


Figure 2: Life-time weighted statistics from DLC 1.2 simulations



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Appendix

Table 1: Selection of environmental conditions for operational design Load Cases (DLCs) from LIFES50+ (Krieger et al., 2006)

U_{ref} [m/s]	5.0	7.1	10.3	13.9	17.9	22.1	25.0
H_s [m]	1.4	1.7	2.2	3.0	4.3	6.2	8.3
T_p [s]	7.0	8.0	8.0	9.5	10.0	12.5	12.0
P %	14%	24%	25%	21%	12%	3.8%	0.74%