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Implementation of the IEA 15 MW turbine in SIMA

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1.1	19th September 2024

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SINTEF Ocean	N/A

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302008154-12	27

Abstract

A RIFLEX-model of the IEA 15 MW reference wind turbine was implemented in SIMA. This documents presents the performance of the model, benchmarked against the OpenFAST models using both the BeamDyn and ElastoDyn modules for blade modelling. In general, good agreement is seen with the OpenFAST models, with closest reasemblance with the BeamDyn model.

PROJECT MEMO NUMBER	CLASSIFICATION
1	Unrestricted

PREPARED BY	APPROVED BY
Jacobus de Vaal, Stian Stensby Sørum	Henning Braathen

Document History

VERSION	DATE	VERSION DESCRIPTION
0.1	27th August 2024	Initial version for QA
0.2	28th August 2024	Updated version for QA
1.0	29th August 2024	Final version
1.1	19th September 2024	Specify controller version used in simulations

Contents

1 Introduction

This memo summarises the verification results of the RIFLEX implementation of the IEA 15 MW reference wind turbine[1]. Verification is performed by calculation of single blade eigenfrequencies, tower and RNA eigenfrequencies, steady-state turbine performance, turbine response to a uniform wind field with wind steps, and turbine response to turbulent wind. In general, good agreement is seen with the OpenFAST[2] models used for verification, with closest resemblance with the response of the OpenFAST model using BeamDyn for modelling the blade structural properties. Comparisons to OpenFAST are performed using:

- OpenFAST v3.5.2, `https://github.com/OpenFAST/openfast/releases/download/v3.5.2/openfast_x64.exe`
- IEA 15MW rotor definition v1.1.7, (git `tags/v1.1.7`, corresponding to commit `#f327b7b`[3])
- ROSCO controller v2.7.0, `https://github.com/NREL/ROSCO/releases/download/v2.7.0/libdiscon.dll`

The same controller configuration fiel was used for the SIMA and OpenFAST simulations, and can be found as part of the SIMA model is available from `https://sintef.github.io/sima-examples-site/`.

2 Blade Properties

The mass of a single blade in the SIMA model is 66.93 metric tons. Table 1 shows the seven lowest eigenfrequencies of the blade, compared to the results achieved with OpenFAST/BeamDyn. In general, good agreement is seen with a slightly to high natural frequency fo the first edgewise mode.

Table 1: Comparison of single blade eigenfrequencies from SIMA and OpenFAST/BeamDyn

Mode	SIMA	BeamDyn	Difference
1st flap	0.4974 Hz	0.5052 Hz	−1.56 %
1st edge	0.6841 Hz	0.6392 Hz	6.78%
2nd flap	1.4386 Hz	1.4904 Hz	−3.54 %
2nd edge	2.0800 Hz	2.1418 Hz	−2.93 %
3rd flap	2.8079 Hz	2.9220 Hz	−3.98 %
1st torsion	4.1102 Hz	4.0966 Hz	0.33%
3rd edge	4.2318 Hz	4.3693 Hz	−3.20 %

3 Turbine and Tower Properties

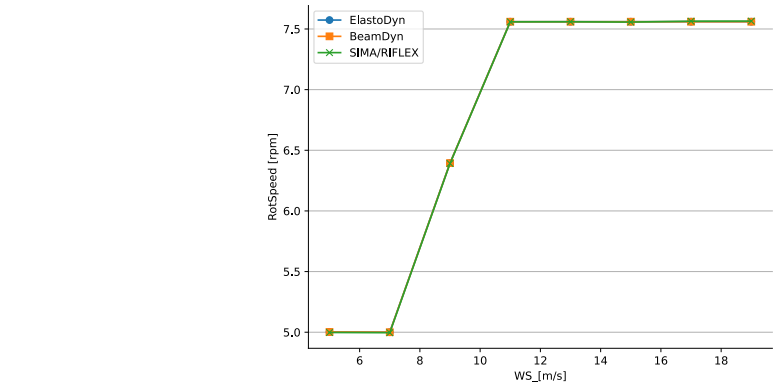
The weight of the RNA in the SIMA model is 945 metric tons, while the weight of the tower is 859 metric tons. Eigenfrequencies of the tower and RNA are given in Table 2. These are calculated with the tower clamped at the tower base, 15 m above the mean water line.

Table 2: Eigenfrequencies of the IEA 15 MW turbine model including tower.

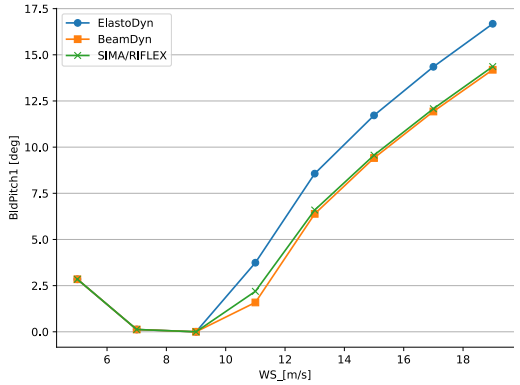
Mode	Eigenfrequency
1st side-side	0.223 Hz
1st fore-aft	0.226 Hz
1st asymmetric flap 1	0.454 Hz
1st asymmetric flap 2	0.491 Hz
1st collective flap	0.516 Hz
1st collective edge	0.627 Hz
1st asymmetric edge 1	0.688 Hz
1st asymmetric edge 2	0.697 Hz
2nd asymmetric flap 1	1.223 Hz
2nd asymmetric flap 2	1.335 Hz
2nd collective flap	1.460 Hz
2nd side-side	1.725 Hz
2nd fore-aft	1.795 Hz

4 Steady State Performance

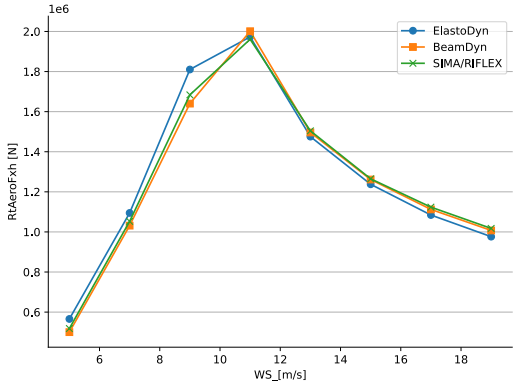
Steady-state rotor speed, blade pitch, generator torque, generator power, and aerodynamic thrust force have been compared for the SIMA model, an OpenFAST model using ElastoDyn and an OpenFAST model using BeamDyn for wind speeds 5 to 19 m/s, with steps of 2 m/s. Figure 1 documents the rotor performance, with good agreement between the SIMA model and the BeamDyn model. As expected, larger discrepancies is seen with the ElastoDyn model.



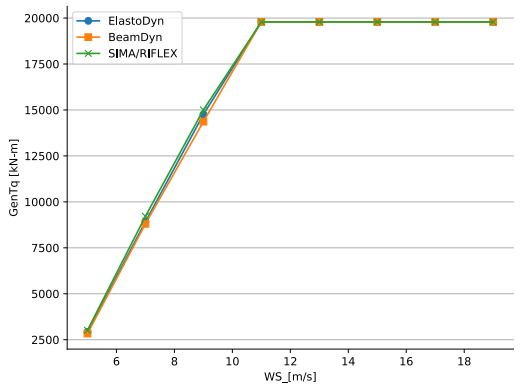
(a) Rotor Speed



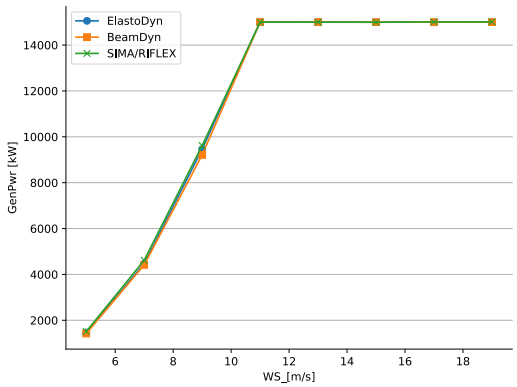
(b) Blade Pitch



(c) Aero. Thrust



(d) Gen. Torque



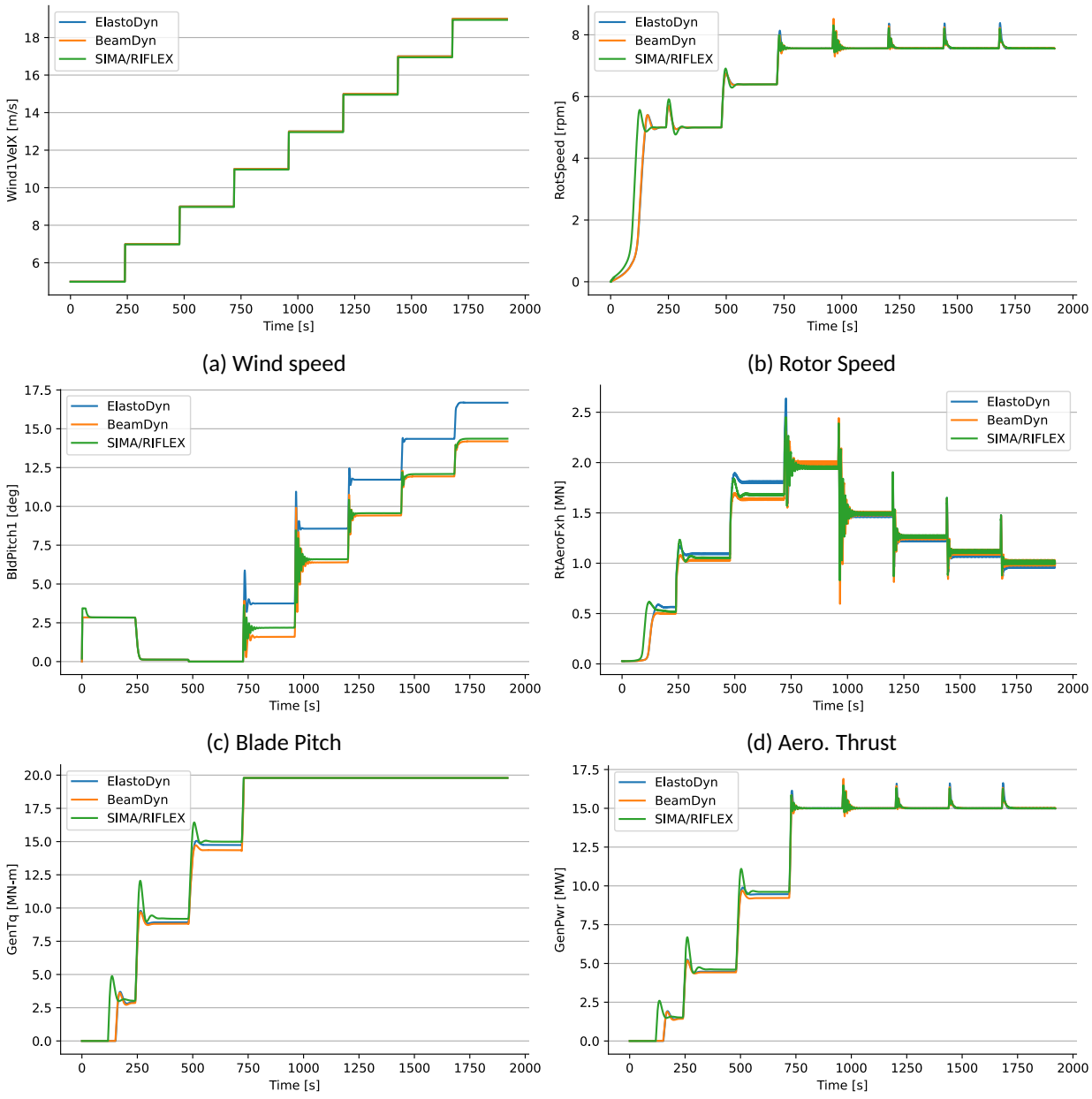
(e) Gen. Power

Figure 1: Steady-state response with a constant, uniform wind field

5 Stepped Wind Response

The wind turbine response in uniform, stepped wind conditions is shown in Figure 2, where the wind speed is increased every $250\,\mathrm{s}$ by $2.0\,\mathrm{m\,s^{-1}}$ over a $1.0\,\mathrm{s}$ interval. Slightly larger transient responses were seen for the SIMA model below rated, with slightly lower transient responses above rated. While not investigated in detail, the observed differences may likely be attributed to further modelling differences between SIMA and OpenFAST:

- Aerodynamic modelling: In the reference OpenFAST AeroDyn module input files of the IEA 15MW turbine, the wake/induction model is set to the steady *[*BEMT] model by default, while RIFLEX uses an implementation more similar to the *[*DBEMT] option. The OpenFAST input may be modified and revised in a future revision.
- Drivetrain modelling: In OpenFAST ElastoDyn, a simple drivetrain model is applied between rotor and generator, whereas this is not accounted for in RIFLEX.



(a) Wind speed

(b) Rotor Speed

(c) Blade Pitch

(d) Aero. Thrust

(e) Gen. Torque

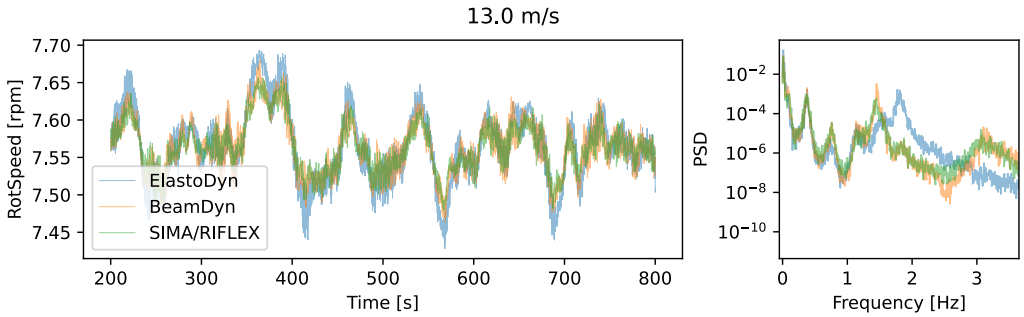
(f) Gen. Power

Figure 2: Response under stepped wind loads

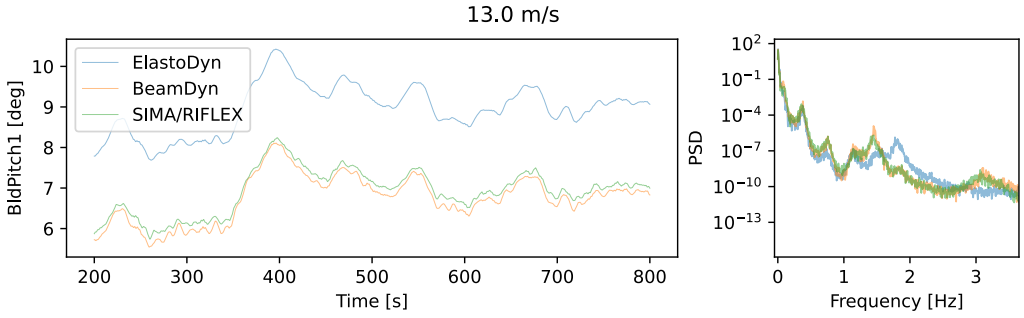
6 Turbulent Wind Response

The response in turbulent wind was compared in time series and power spectral density plots (Figure 3 and Appendix A). In general, good agreement was seen between BeamDyn and SIMA, with slight deviations for higher frequencies (above approx. 2 Hz) and close to rated wind speed. The differences at higher frequencies are believed to be caused by different coupling of the torsion and bending modes. It should also be noted that the power spectrum plots are with a logarithmic y-axis, so the response at these frequencies are very low. The differences close to rated speed were expected as operation at rated wind speed is sensitive to the time evolution of turbine response and wind loading. Furthermore, the modelling differences mentioned in Section 5 also apply here.

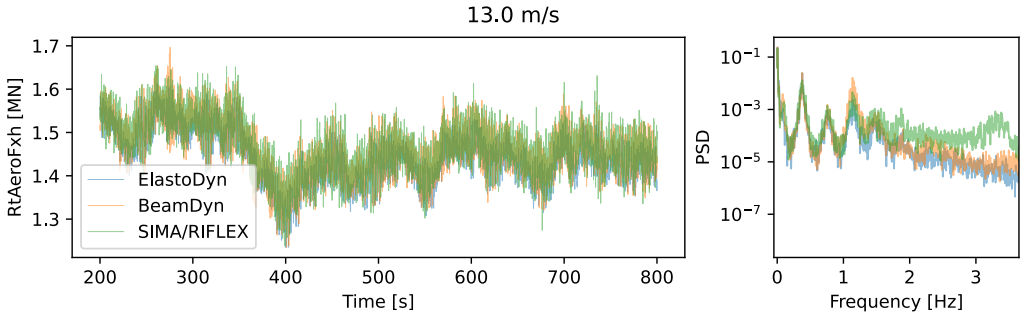
Violin plots are also presented in Figures 4 to 10, showing the distribution of the response. As for the stepped wind response, BeamDyn and SIMA show similar results, with the largest deviations seen at rated wind speed.



(a) Rotor Speed



(b) Blade pitch



(c) Aero. Thrust

Figure 3: Time series and power spectral density plots of selected signals for mean wind speed $13.0\,\mathrm{m\,s^{-1}}$.

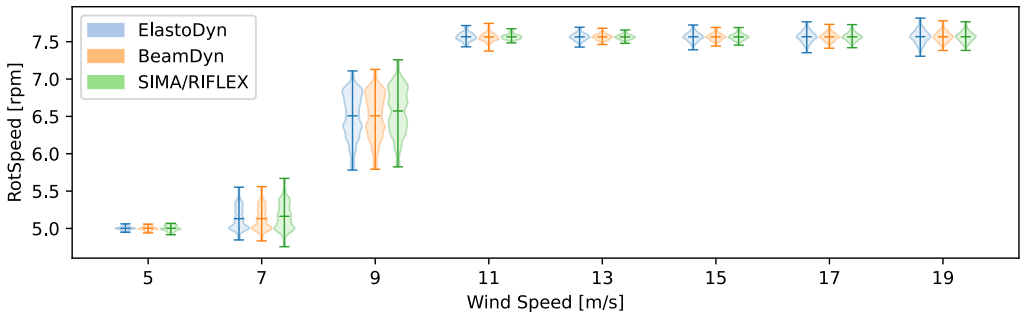


Figure 4: Rotor Speed

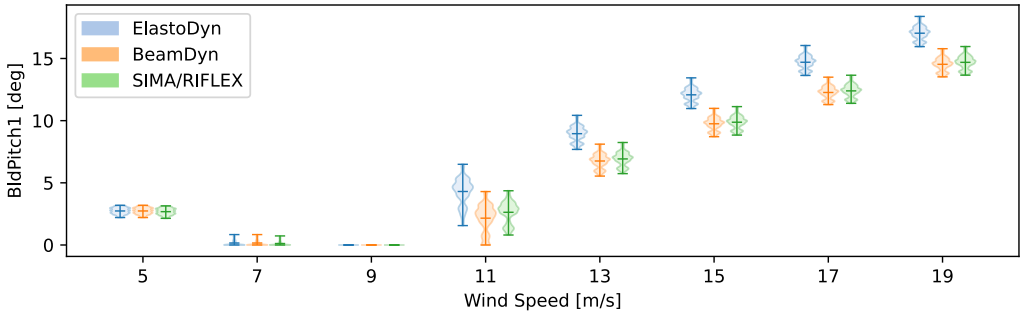


Figure 5: Blade Pitch

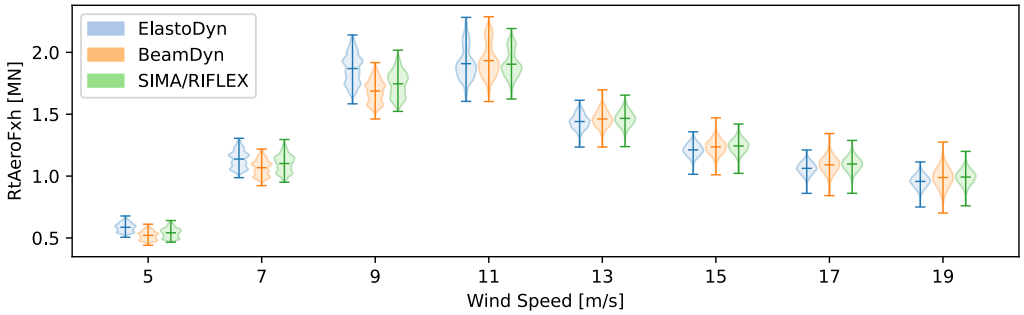


Figure 6: Aero. Thrust

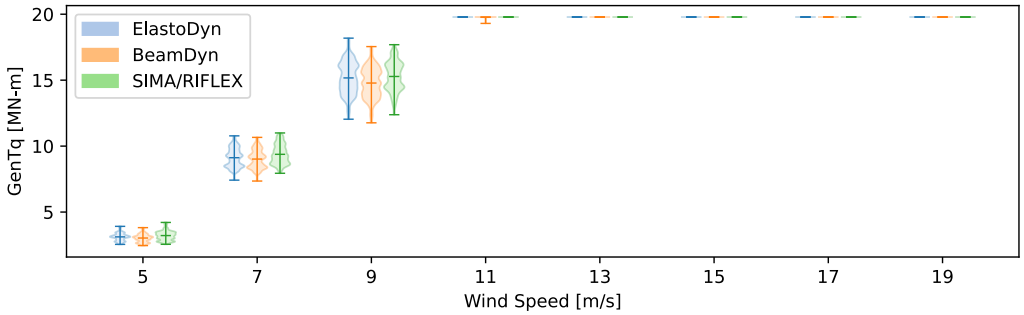


Figure 7: Gen. Torque

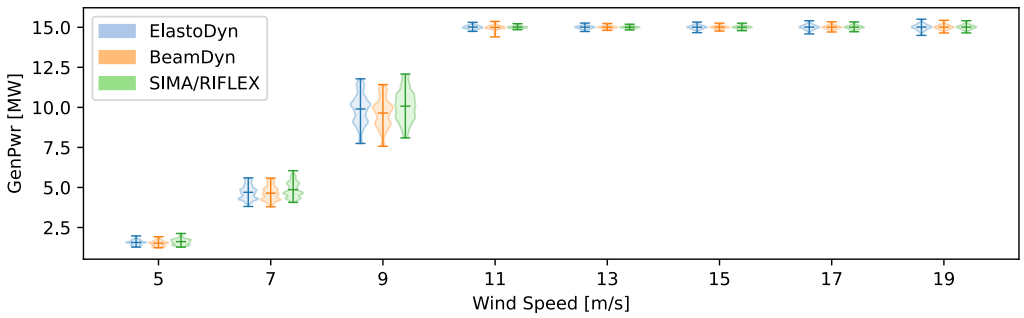


Figure 8: Gen. Power

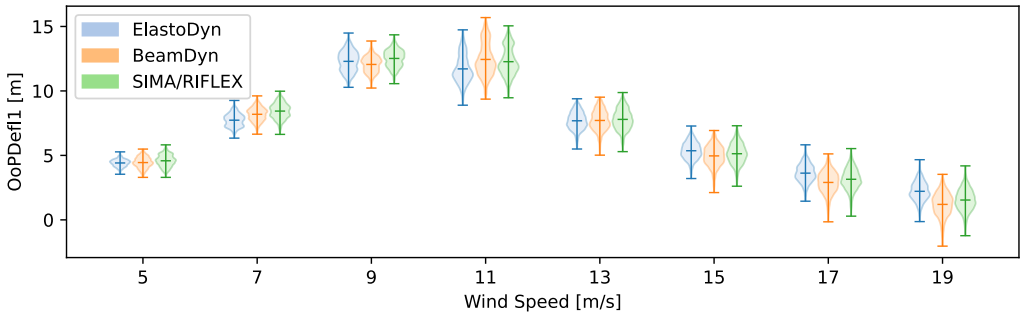


Figure 9: Blade tip out of plane deflection

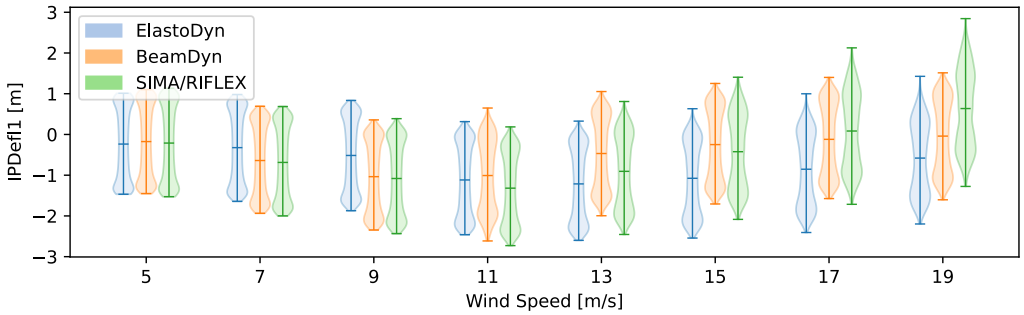


Figure 10: Blade tip in plane deflection

References

[1] Evan Gaertner et al. *Definition of the IEA Wind 15-Megawatt Offshore Reference Wind Turbine*. National Renewable Energy Laboratory, 2020. URL: https://www.nrel.gov/docs/fy20osti/75698.pdf (visited on 21/08/2024).

[2] *OpenFAST Documentation — OpenFAST v3.5.3 documentation*. URL: https://openfast.readthedocs.io/en/main/ (visited on 22/08/2024).

[3] *IEAWindTask37/IEA-15-240-RWT*. original-date: 2019-10-08T15:18:15Z. 15th Aug. 2024. URL: https://github.com/IEAWindTask37/IEA-15-240-RWT (visited on 23/08/2024).

A Time Series and PSD Plots of Turbulent Wind Reponse

A.1 Mean Wind Speed 5 m/s

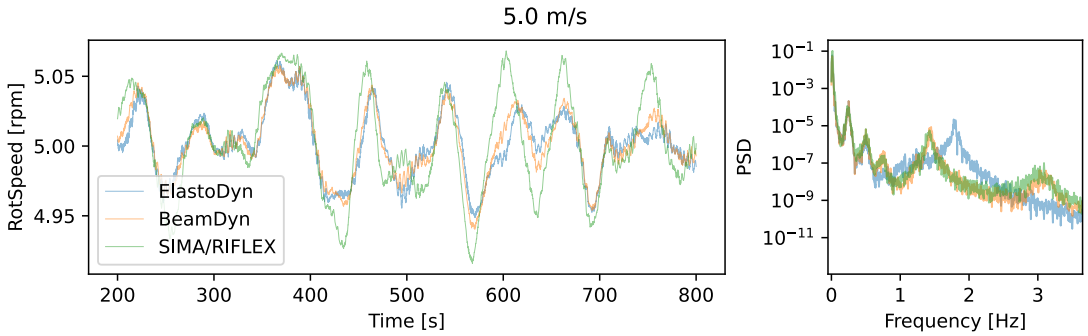


Figure 11: Rotor speed

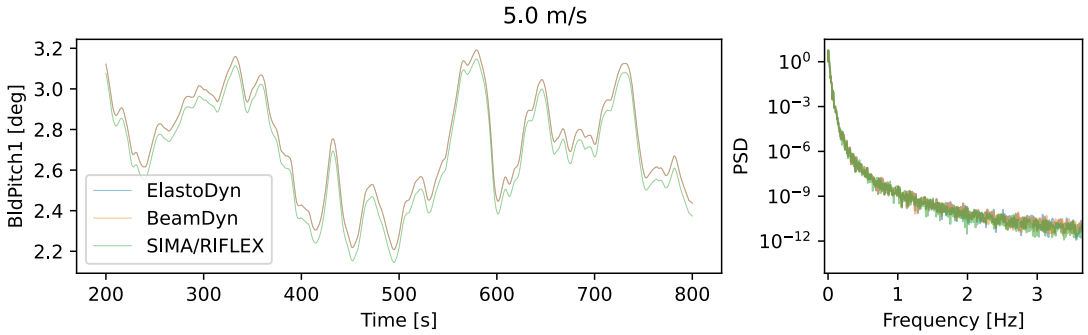


Figure 12: Blade pitch

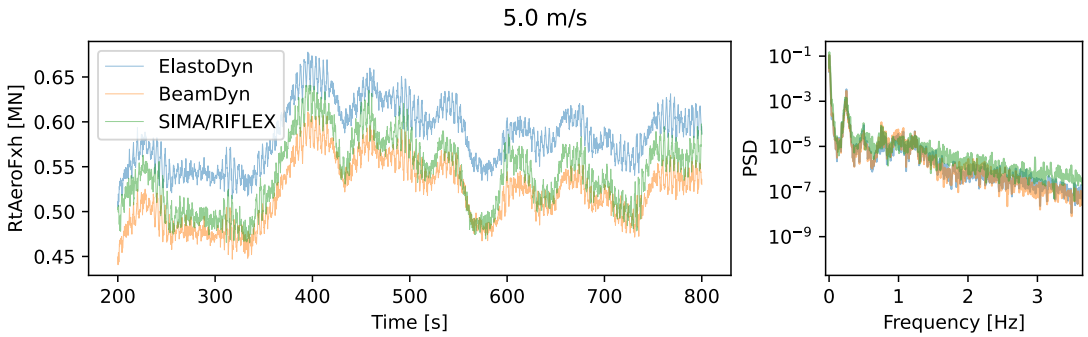


Figure 13: Aero. thrust

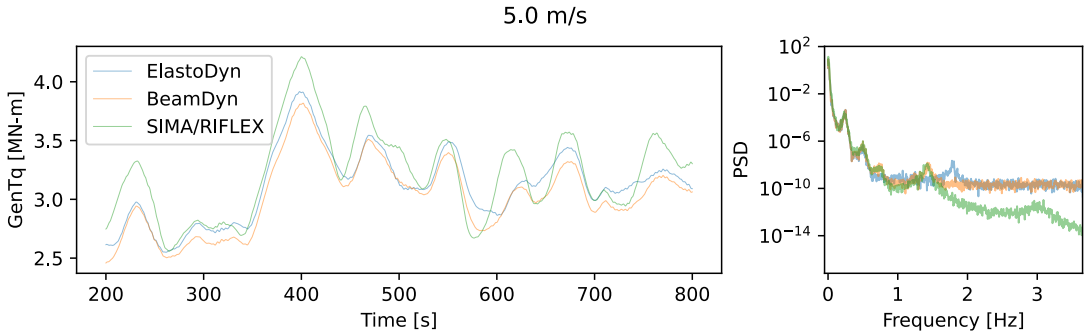


Figure 14: Generator torque

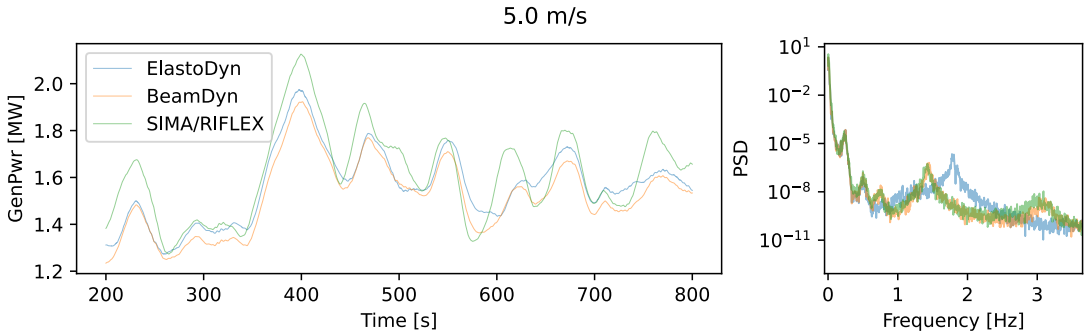


Figure 15: Generator power

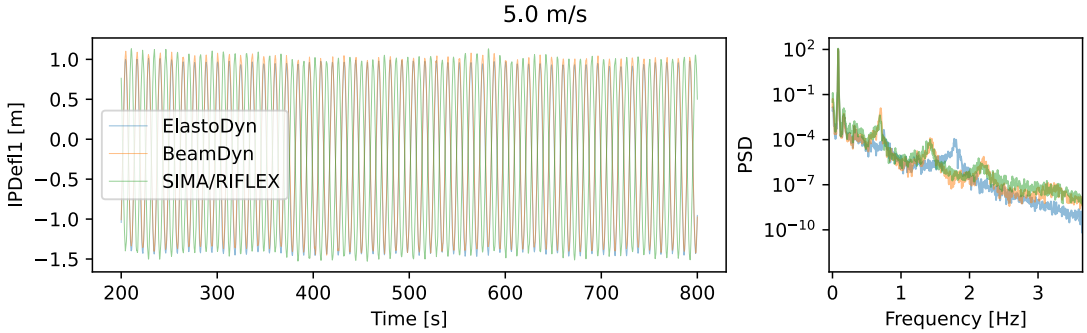


Figure 16: Blade 1 in-plane blade tip deflection

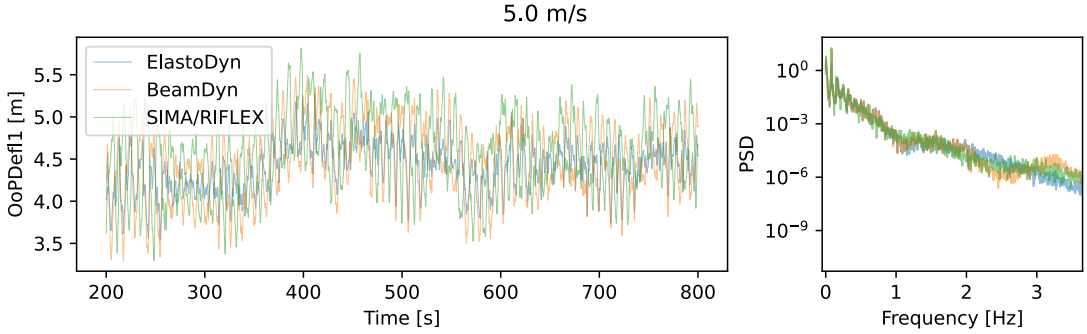


Figure 17: Blade 1 out-of-plane blade tip deflection

A.2 Mean Wind Speed 7 m/s

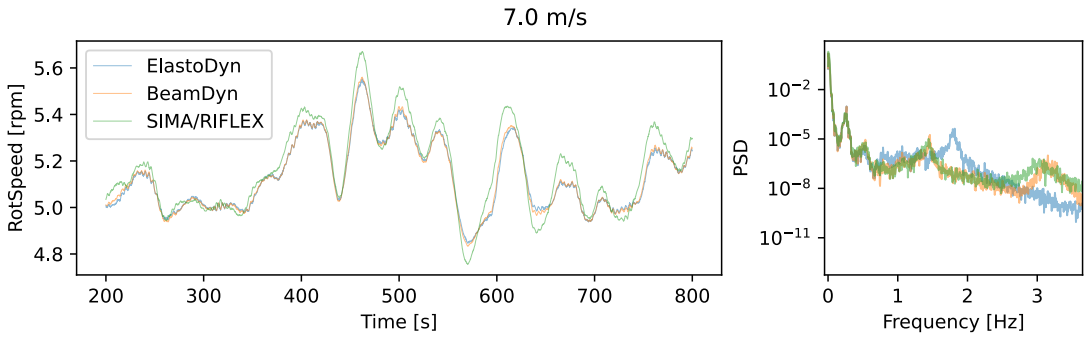


Figure 18: Rotor speed

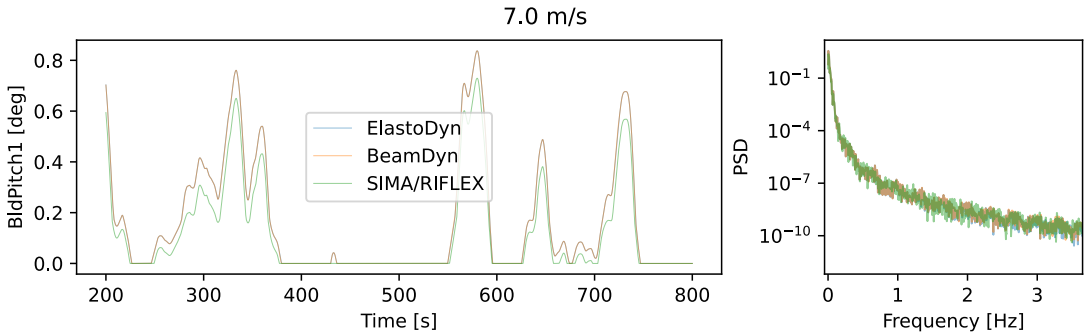


Figure 19: Blade pitch

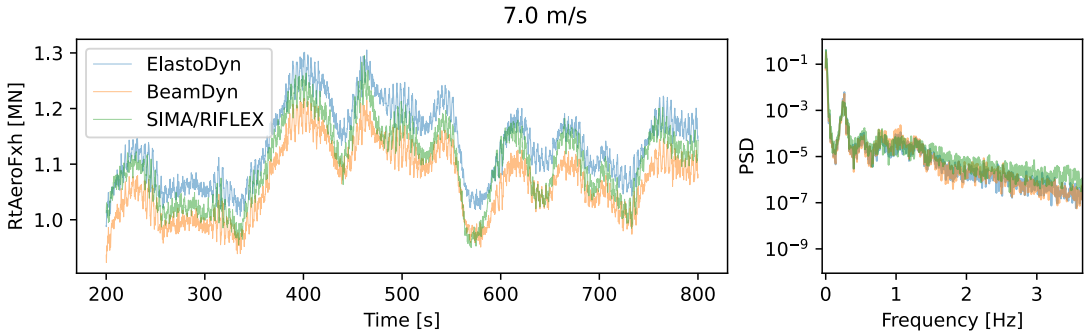


Figure 20: Aero. thrust

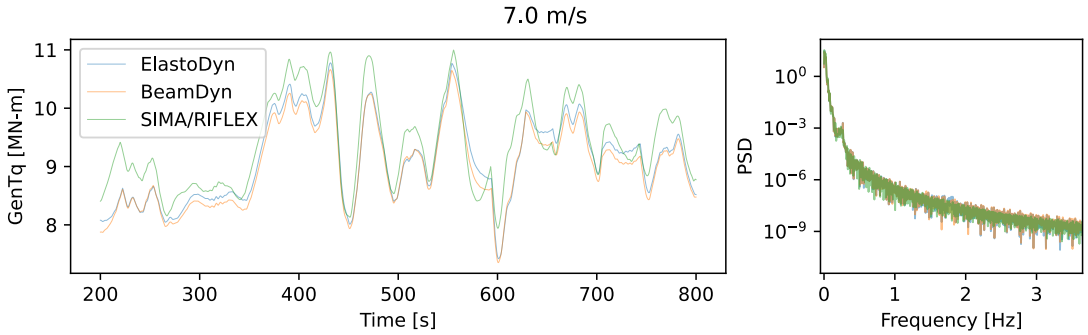


Figure 21: Generator torque

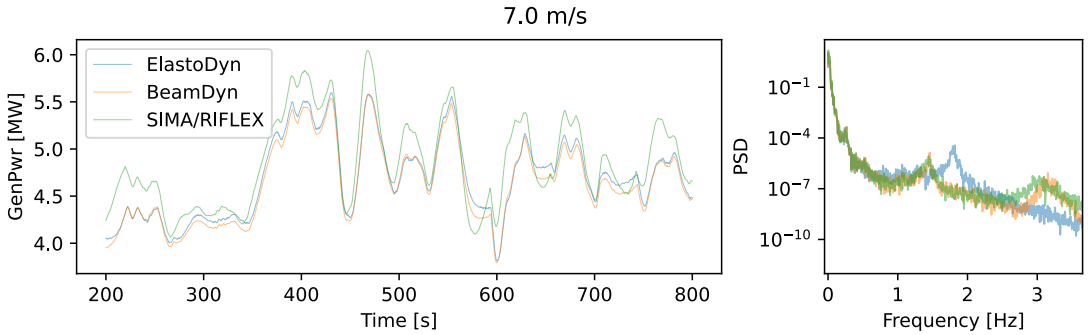


Figure 22: Generator power

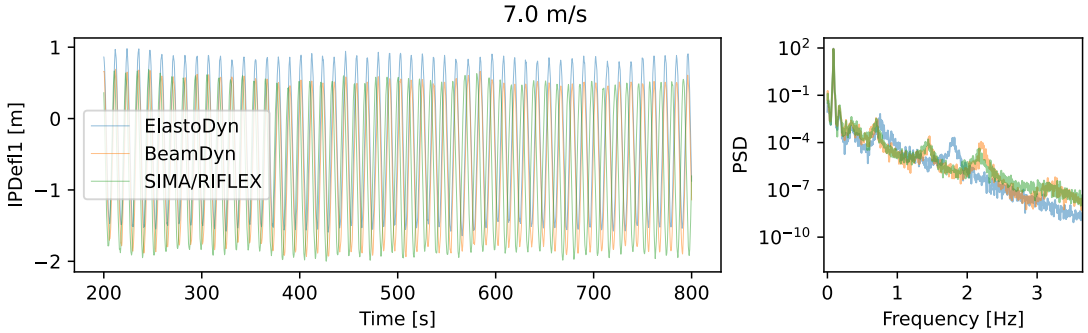


Figure 23: Blade 1 in-plane blade tip deflection

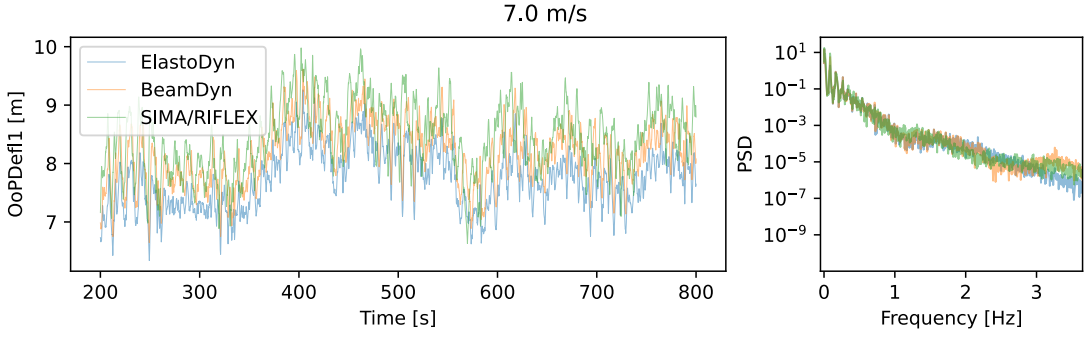


Figure 24: Blade 1 out-of-plane blade tip deflection

A.3 Mean Wind Speed 9 m/s

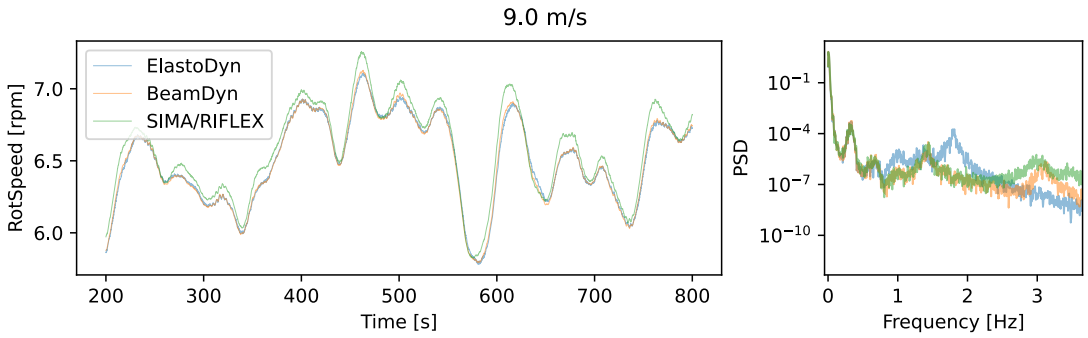


Figure 25: Rotor speed

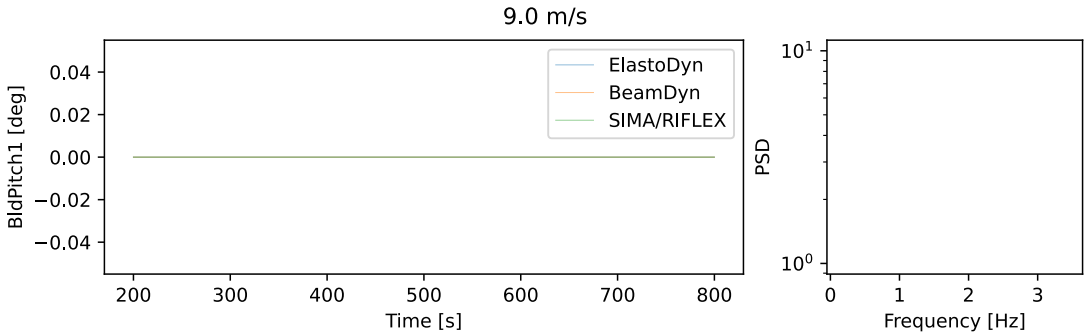


Figure 26: Blade pitch

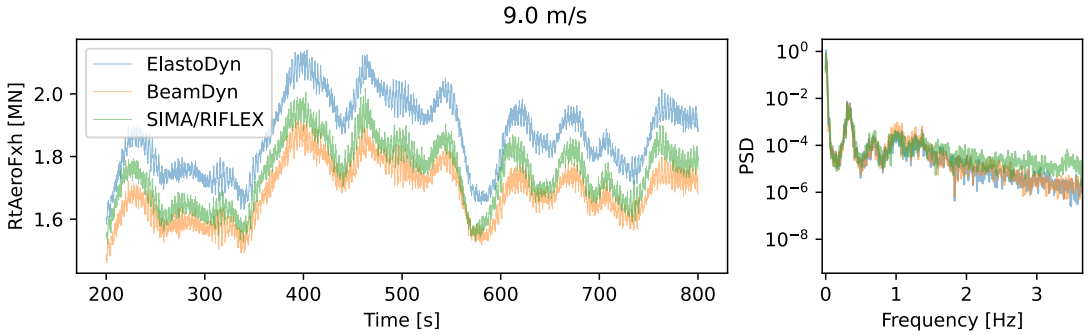


Figure 27: Aero. thrust

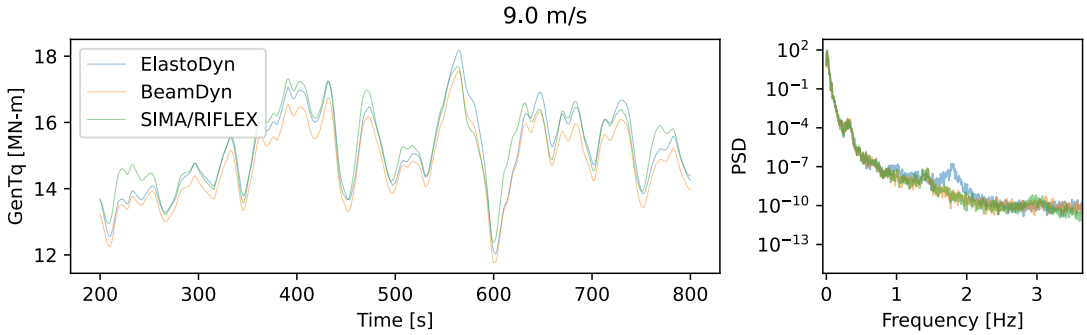


Figure 28: Generator torque

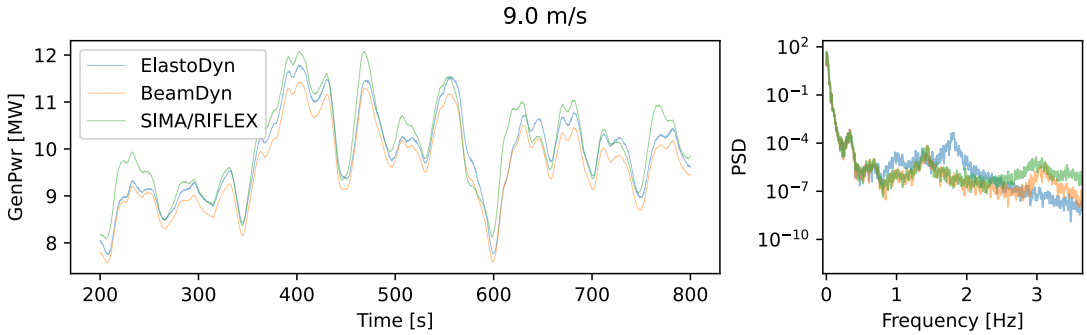


Figure 29: Generator power

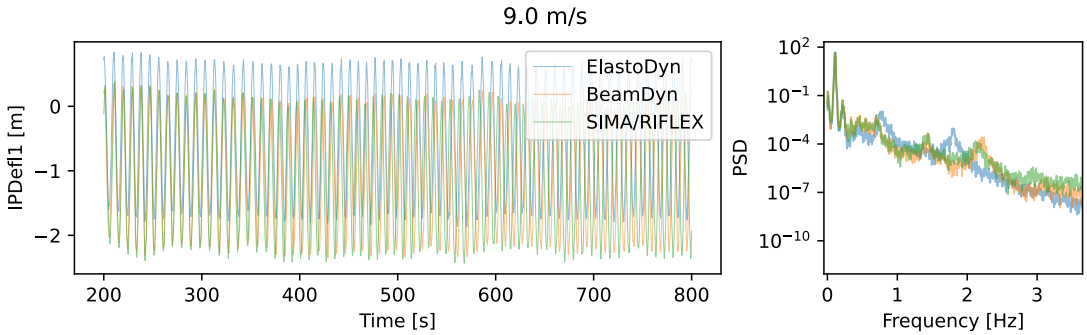


Figure 30: Blade 1 in-plane blade tip deflection

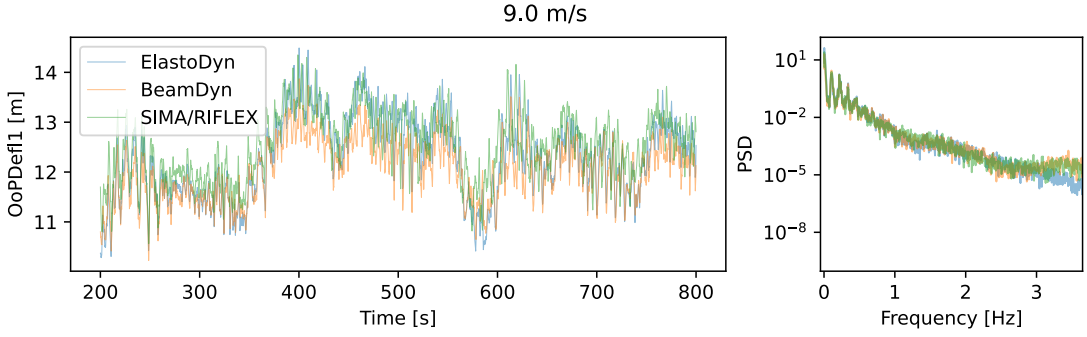


Figure 31: Blade 1 out-of-plane blade tip deflection

A.4 Mean Wind Speed 11 m/s

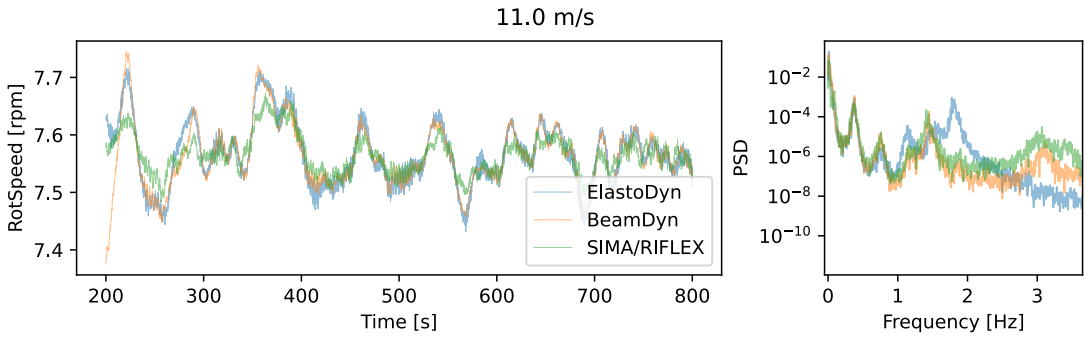


Figure 32: Rotor speed

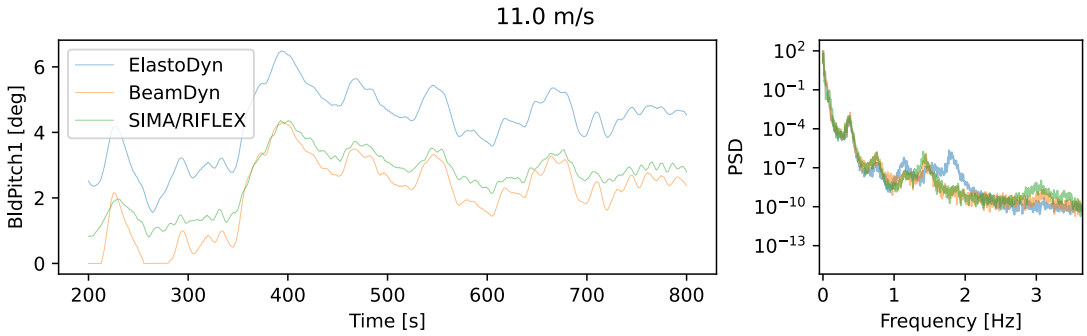


Figure 33: Blade pitch

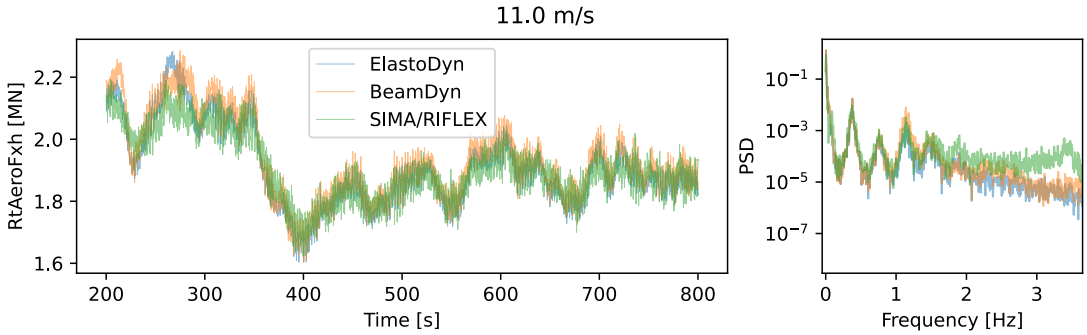


Figure 34: Aero. thrust

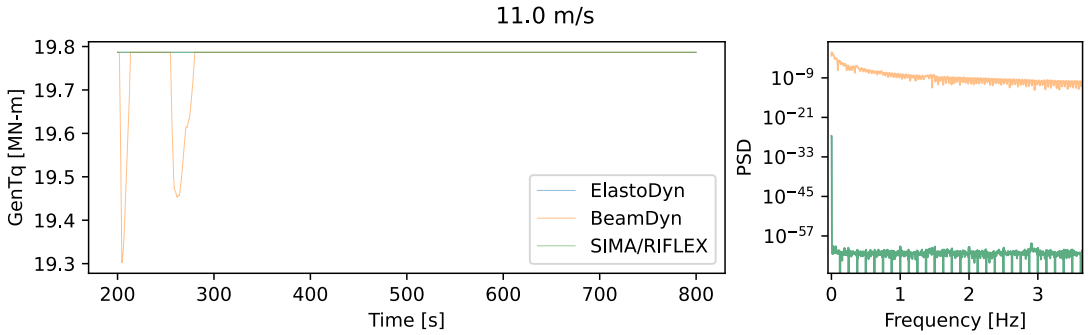


Figure 35: Generator torque

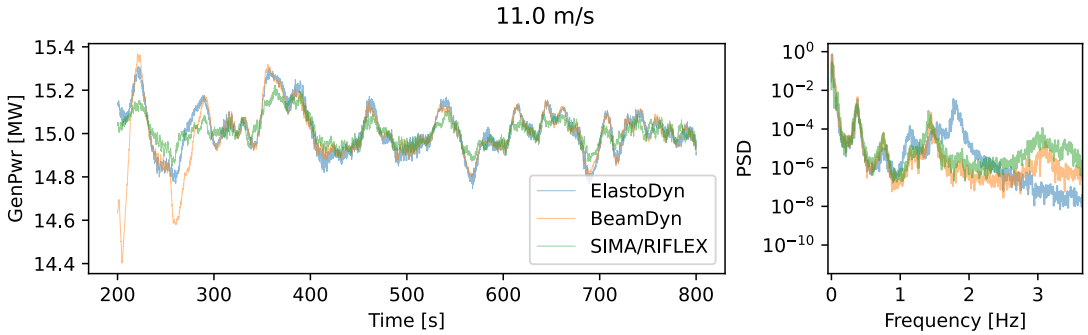


Figure 36: Generator power

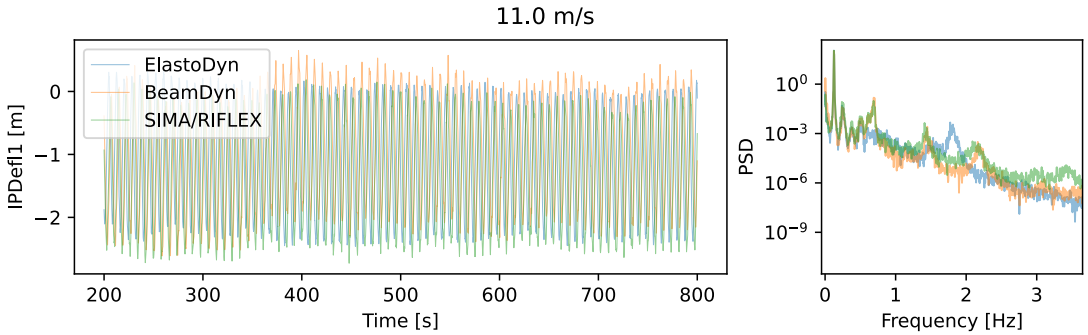


Figure 37: Blade 1 in-plane blade tip deflection

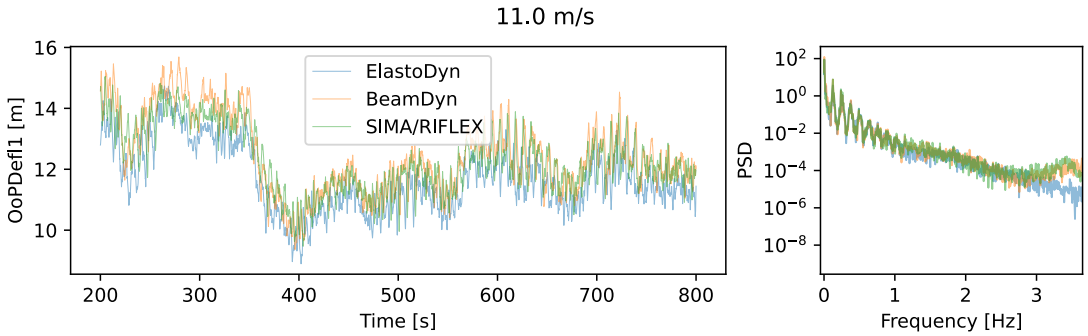


Figure 38: Blade 1 out-of-plane blade tip deflection

A.5 Mean Wind Speed 13 m/s

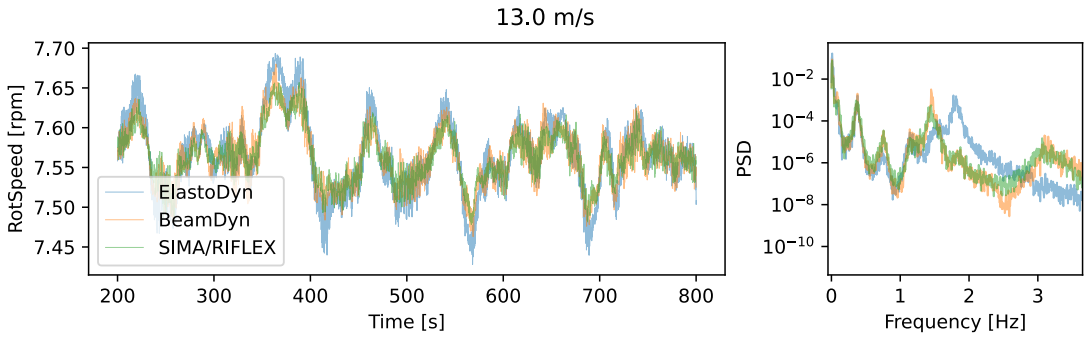


Figure 39: Rotor speed

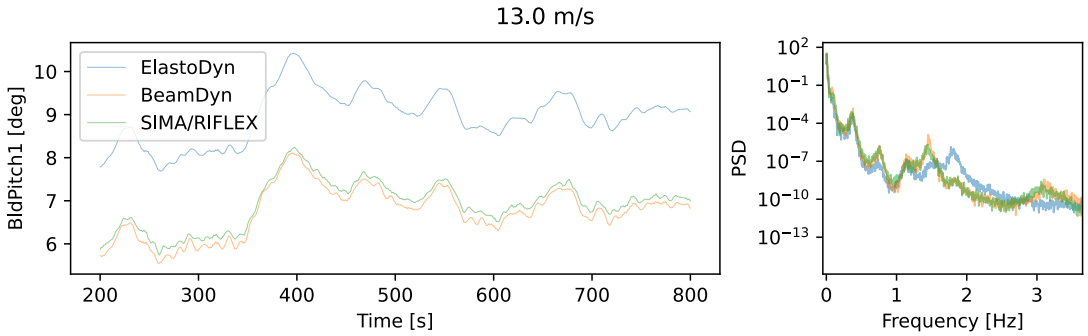


Figure 40: Blade pitch

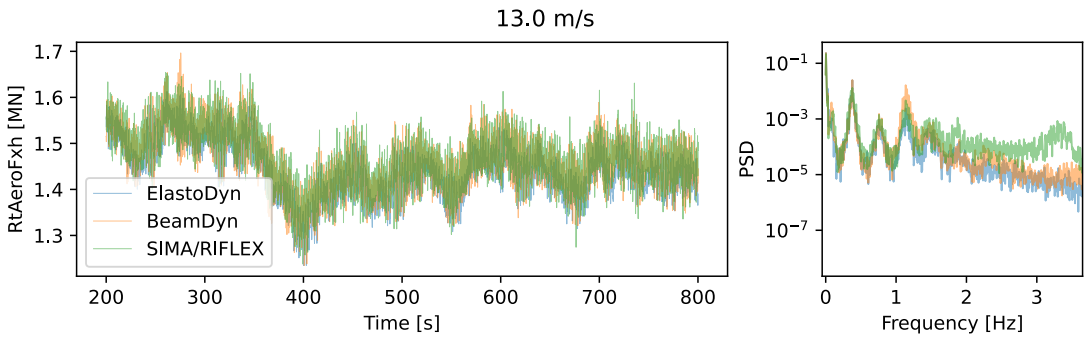


Figure 41: Aero. thrust

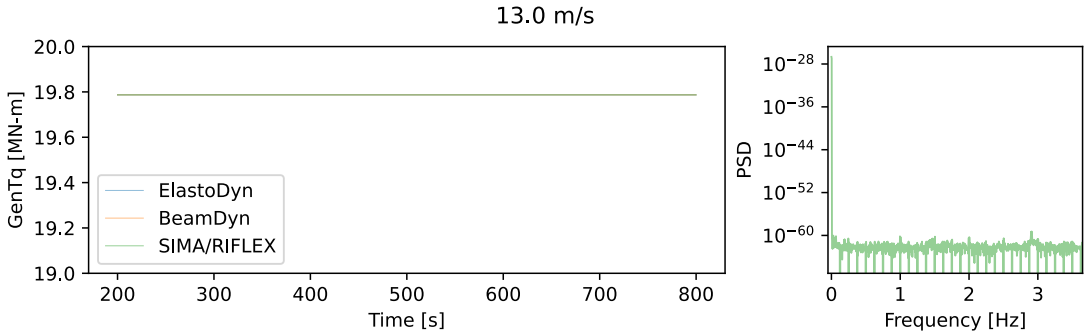


Figure 42: Generator torque

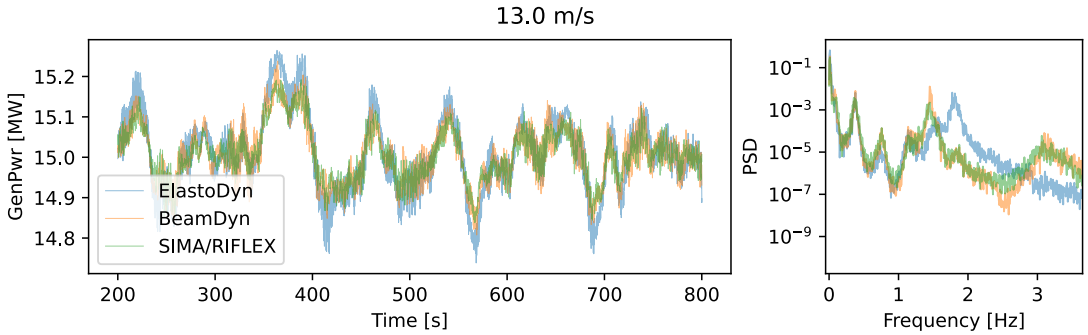


Figure 43: Generator power

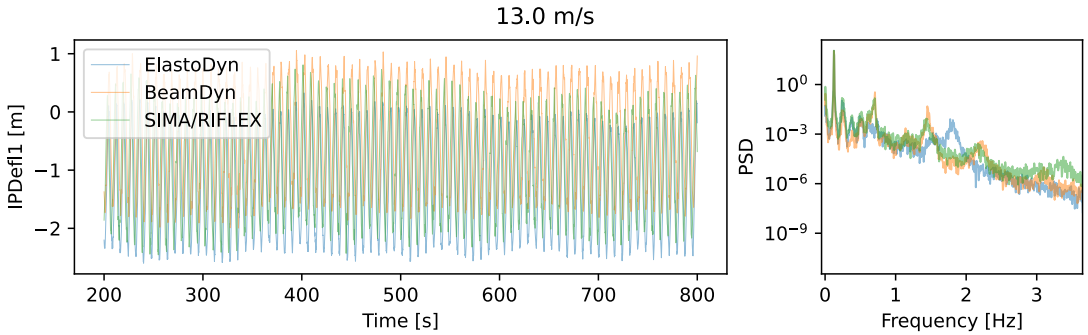


Figure 44: Blade 1 in-plane blade tip deflection

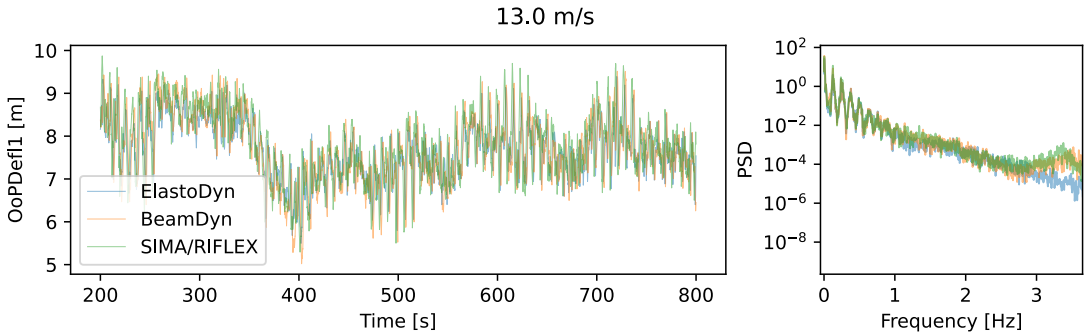


Figure 45: Blade 1 out-of-plane blade tip deflection

A.6 Mean Wind Speed 15 m/s

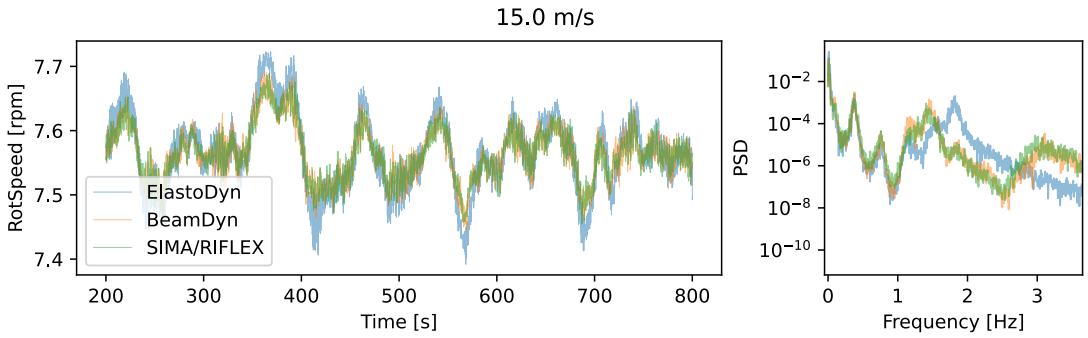


Figure 46: Rotor speed

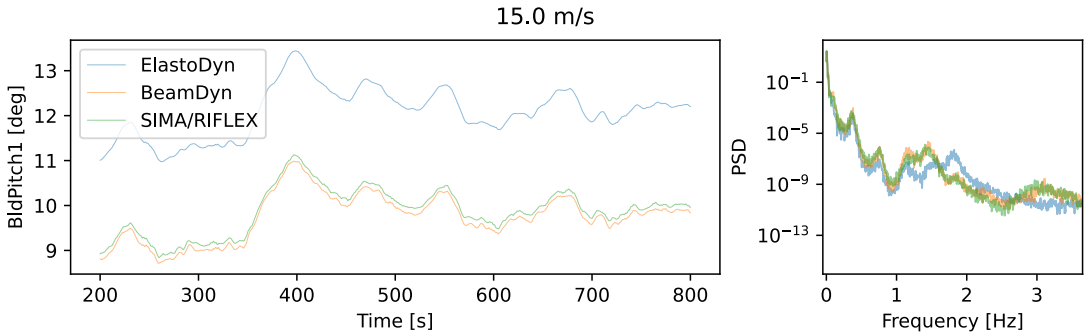


Figure 47: Blade pitch

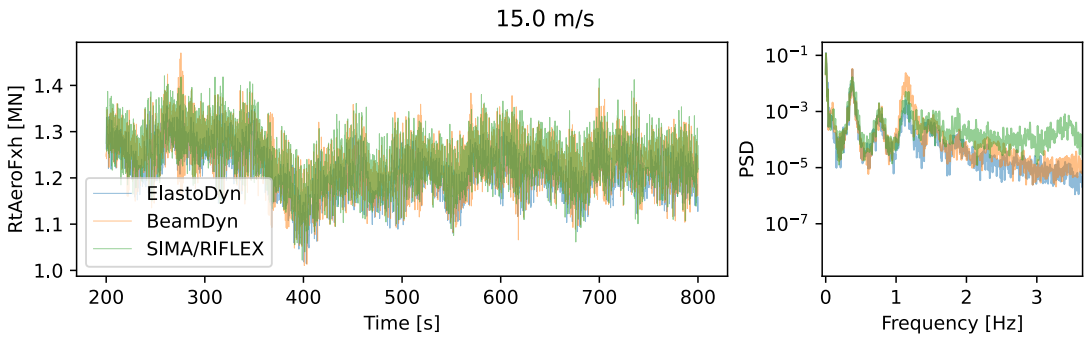


Figure 48: Aero. thrust

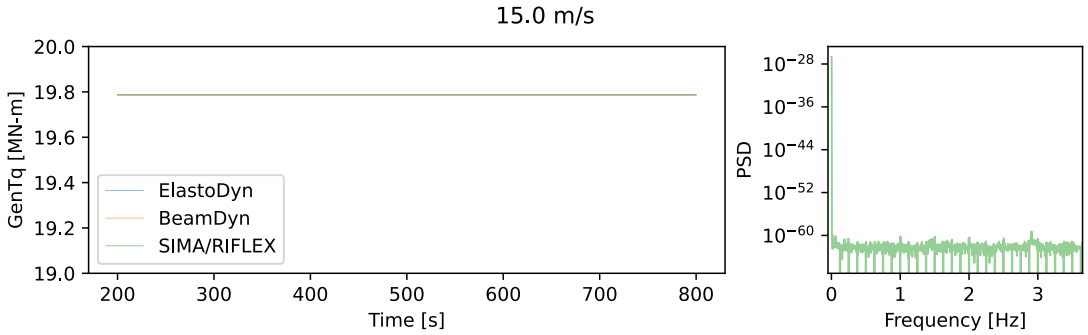


Figure 49: Generator torque

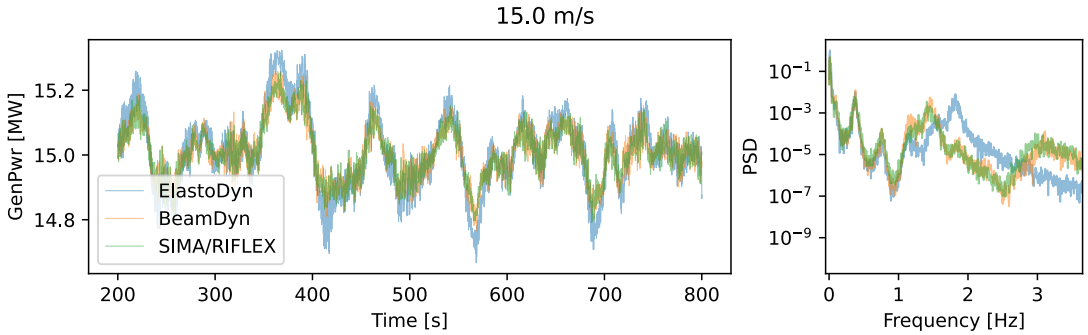


Figure 50: Generator power

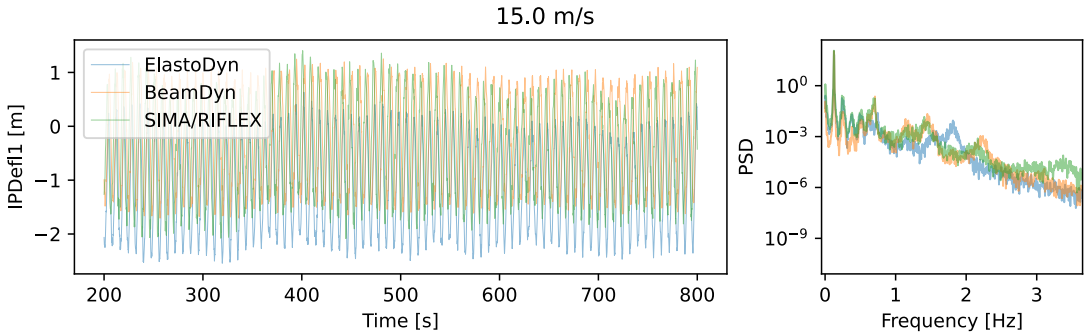


Figure 51: Blade 1 in-plane blade tip deflection

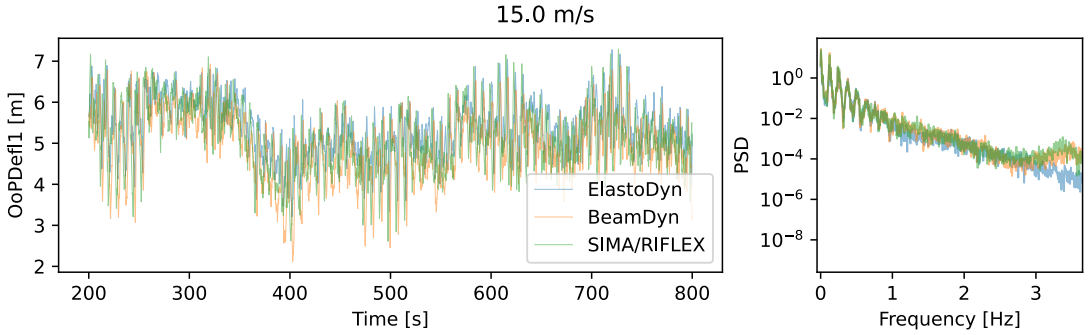


Figure 52: Blade 1 out-of-plane blade tip deflection

A.7 Mean Wind Speed 17 m/s

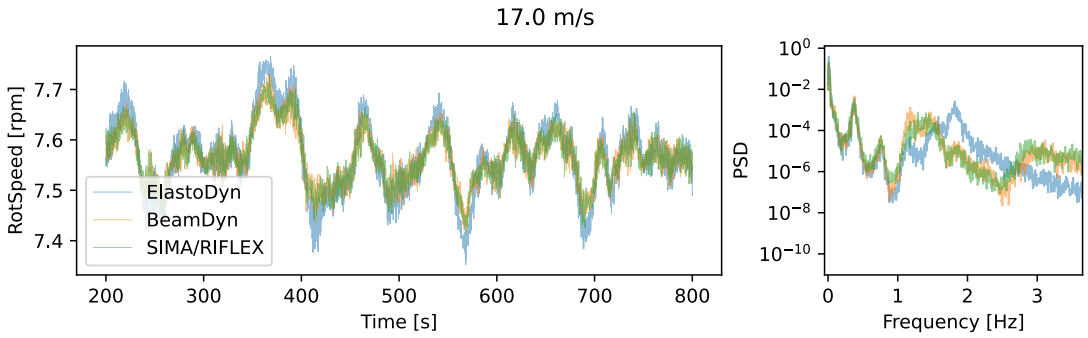


Figure 53: Rotor speed

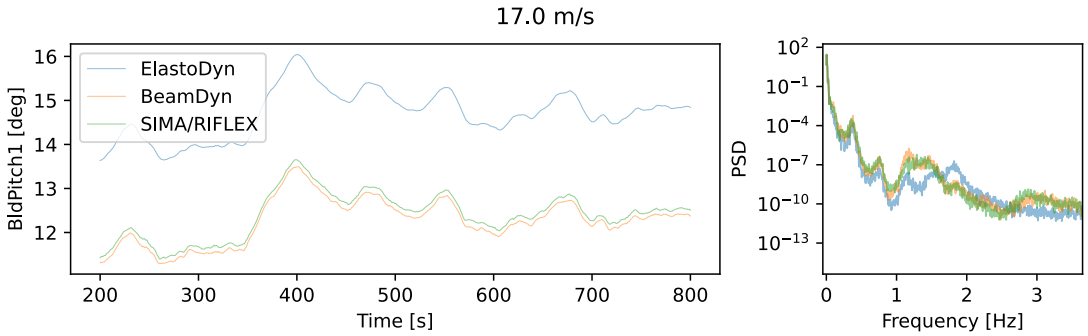


Figure 54: Blade pitch

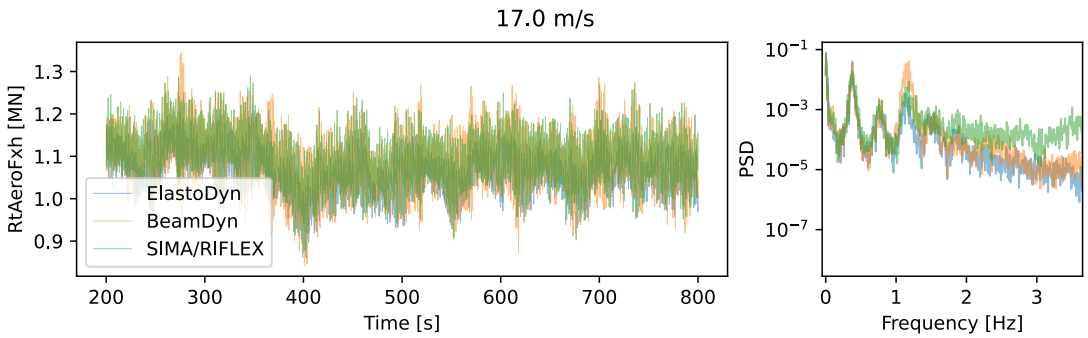


Figure 55: Aero. thrust

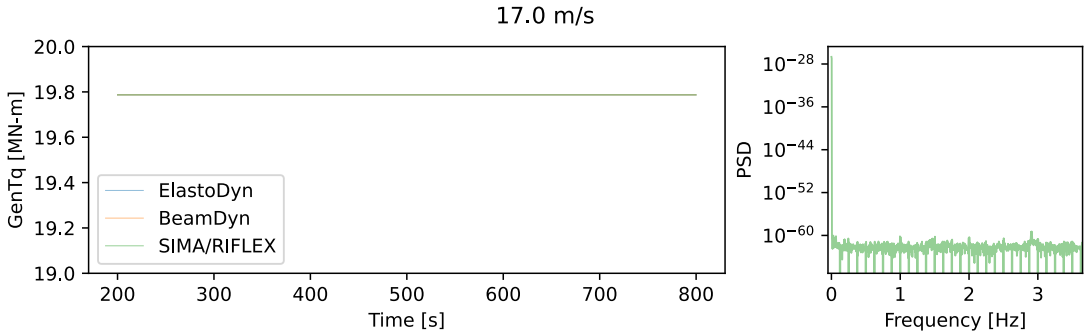


Figure 56: Generator torque

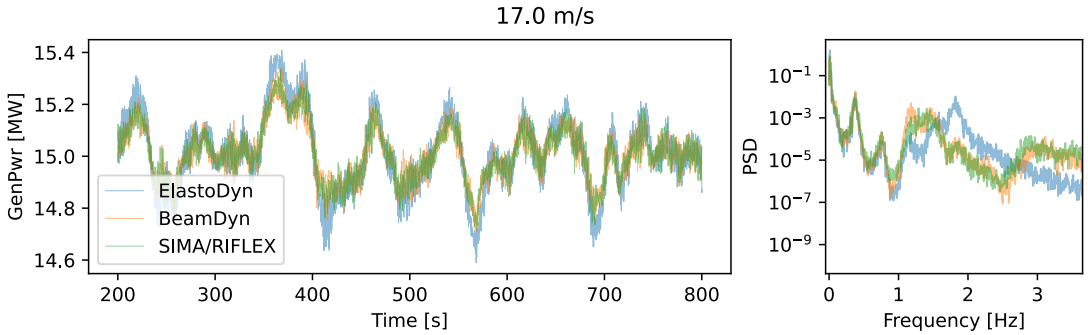


Figure 57: Generator power

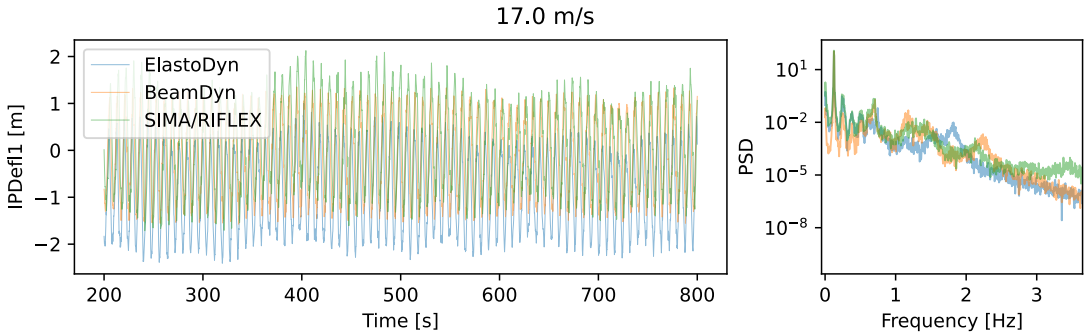


Figure 58: Blade 1 in-plane blade tip deflection

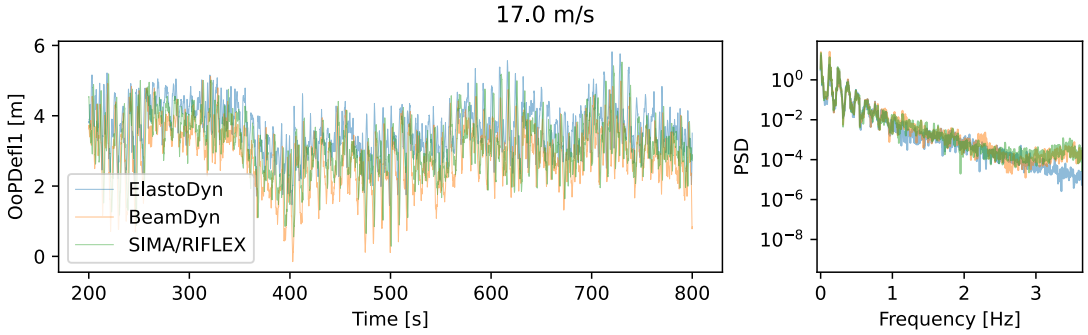


Figure 59: Blade 1 out-of-plane blade tip deflection

A.8 Mean Wind Speed 19 m/s

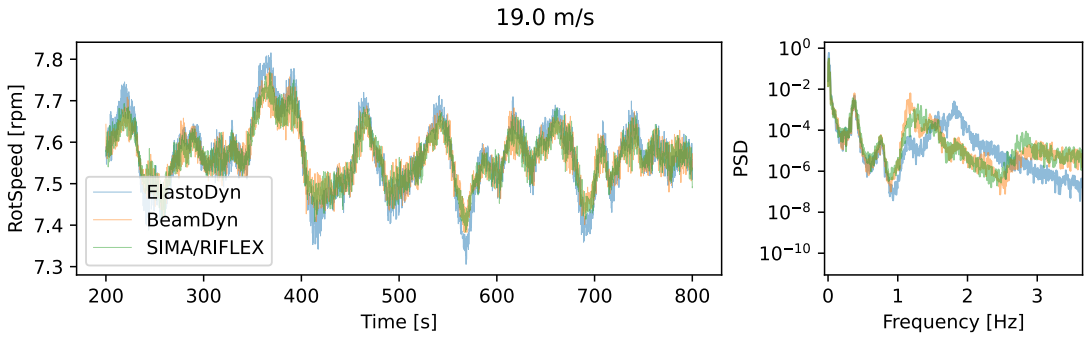


Figure 60: Rotor speed

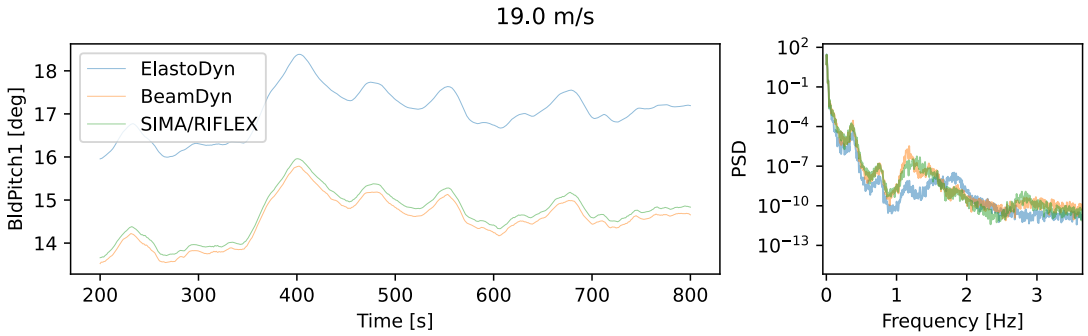


Figure 61: Blade pitch

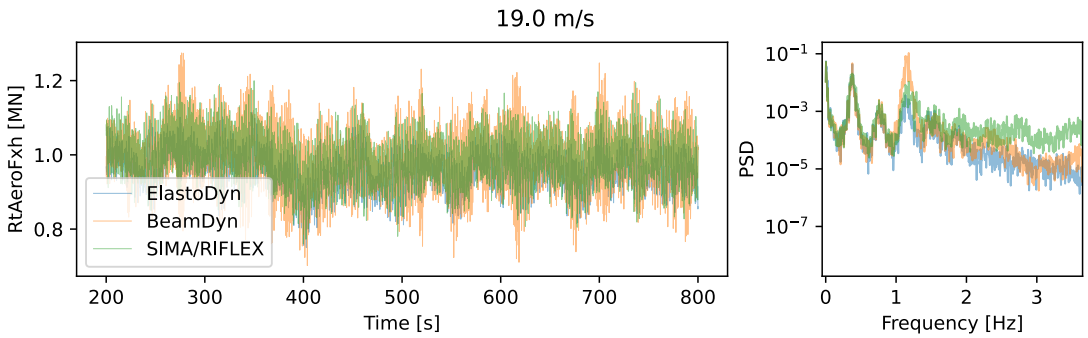


Figure 62: Aero. thrust

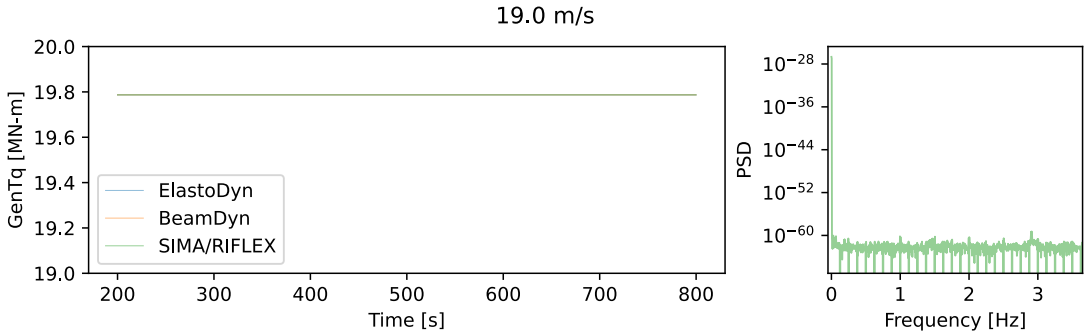


Figure 63: Generator torque

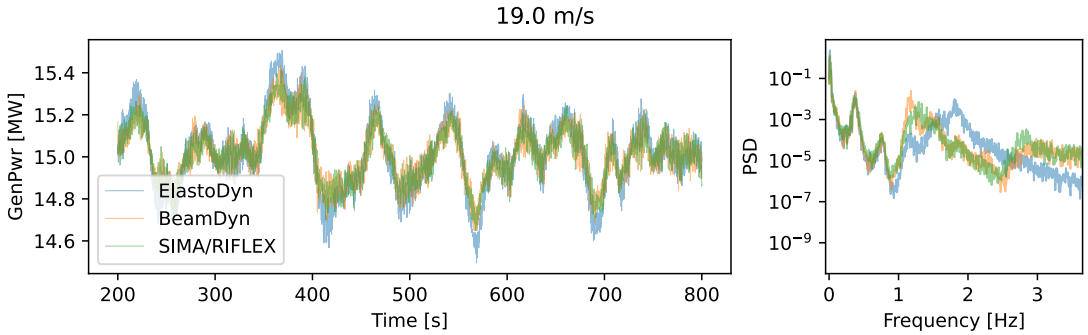


Figure 64: Generator power

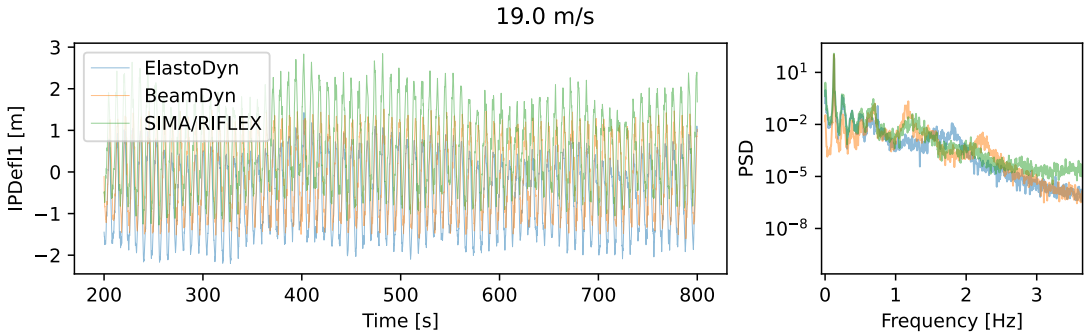


Figure 65: Blade 1 in-plane blade tip deflection

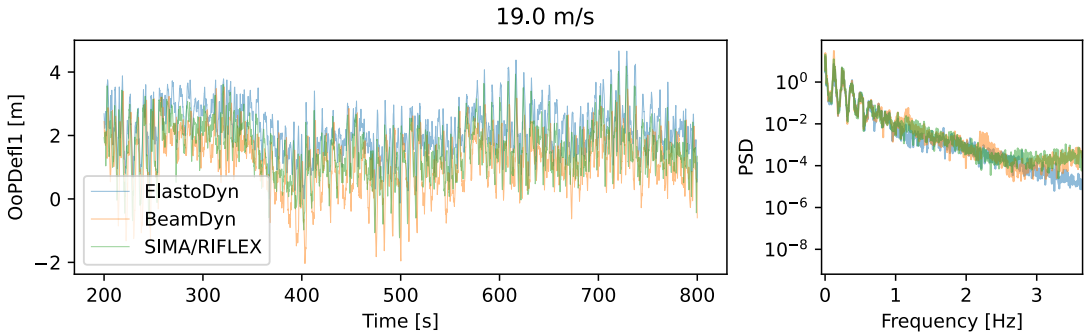


Figure 66: Blade 1 out-of-plane blade tip deflection