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Project Memo

Implementation of the IEA 22 MW turbine in SIMA

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Abstract

A coupled SIMO-RIFLEX-model of the IEA 22 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 to the BeamDyn model.

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PREPARED BY Stian S. Sørum	Signature
APPROVED BY Hagbart S. Alsos	Signature
PROJECT MEMO NUMBER 1	**CLASSIFICATION** Unrestricted

Document History

VERSION	DATE	VERSION DESCRIPTION
0.1	21st May 2025	Initial version for QA
1.0	28th May 2025	Version for publication

Contents

1 Introduction

This memo summarises the verification results of the coupled SIMO-RIFLEX implementation of the IEA 22 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 to the response of the OpenFAST model using BeamDyn for modelling the blade structural properties. Comparisons to OpenFAST are performed using:

- OpenFAST v3.5.5, `https://github.com/OpenFAST/openfast/releases/download/v3.5.5/openfast_x64.exe`
- IEA 22 MW rotor definition commit `#342f71a cd02a11`[3]
- ROSCO controller v2.9.0, `https://github.com/NREL/ROSCO/releases/download/v2.9.0/libdiscon.dll`

The SIMA model is available from `https://sintef.github.io/sima-examples-site/` or from the examples distributed with SIMA.

2 Blade Properties

The mass of a single blade in the SIMA model is 82.6 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.

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

Mode	SIMA	BeamDyn	Difference
1st flap	0.379 Hz	0.381 Hz	0.5%
1st edge	0.516 Hz	0.516 Hz	0.1%
2nd flap	1.045 Hz	1.061 Hz	1.4%
2nd edge	1.478 Hz	1.490 Hz	0.8%
3rd flap	2.166 Hz	2.224 Hz	2.6%
3rd edge	3.167 Hz	3.213 Hz	1.5%
1st torsion	3.976 Hz	3.984 Hz	0.2%

3 Turbine and Tower Properties

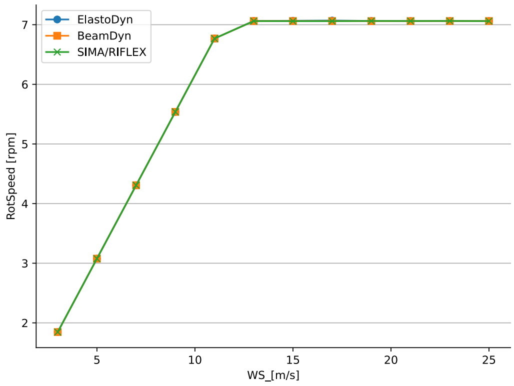
The weight of the RNA in the SIMA model is 1190 metric tons, while the weight of the tower is 1577.5 metric tons. Eigenfrequencies of the tower and RNA are given in Table 2. These are calculated with the tower clamped at the tower base, 15 m above the mean water line.

Table 2: Eigenfrequencies of the IEA 22 MW turbine model including tower.

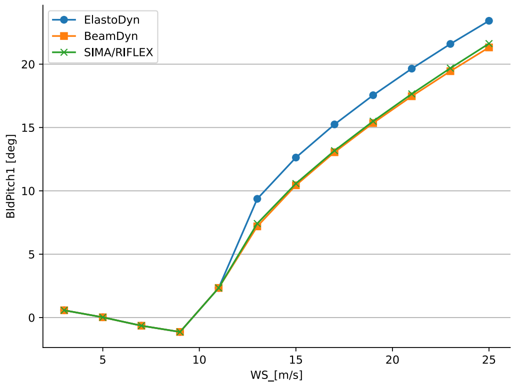
Mode	Eigenfrequency
1st side-side	0.204 Hz
1st fore-aft	0.207 Hz
1st asymmetric flap 1	0.355 Hz
1st asymmetric flap 2	0.377 Hz
1st collective flap	0.397 Hz
1st collective edge	0.429 Hz
1st asymmetric edge 1	0.520 Hz
1st asymmetric edge 2	0.526 Hz
2nd asymmetric flap 1	0.913 Hz
2nd asymmetric flap 2	0.983 Hz
2nd collective flap	1.065 Hz

4 Steady State Performance

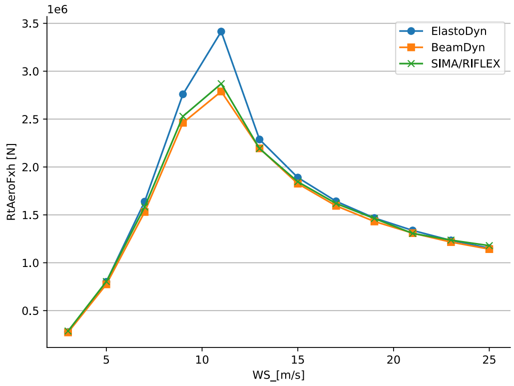
Steady-state rotor speed, blade pitch, generator torque, generator power, and aerodynamic thrust force have been compared for the SIMA model, an OpenFAST model using ElastoDyn and an OpenFAST model using BeamDyn for wind speeds 3 to 25 m/s, with steps of 2 m/s. Figure 1 documents the rotor performance, with good agreement between the SIMA model and the BeamDyn model. As expected, larger discrepancies is seen with the ElastoDyn model.



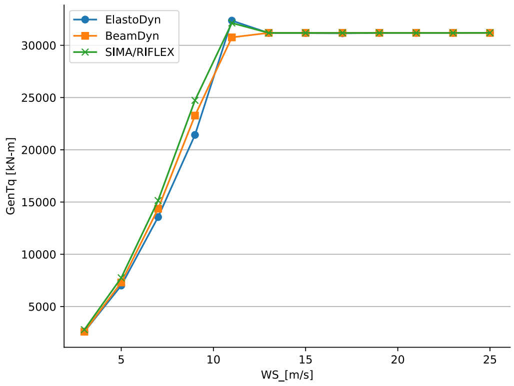
(a) Rotor Speed



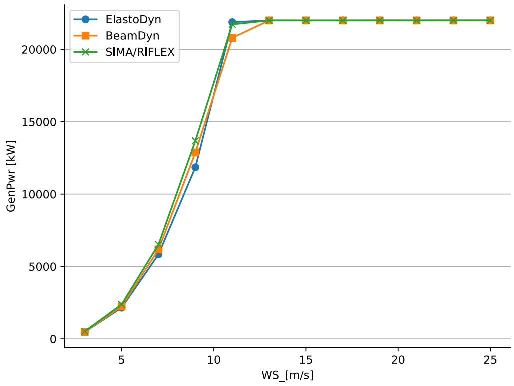
(b) Blade Pitch



(c) Aero. Thrust



(d) Gen. Torque



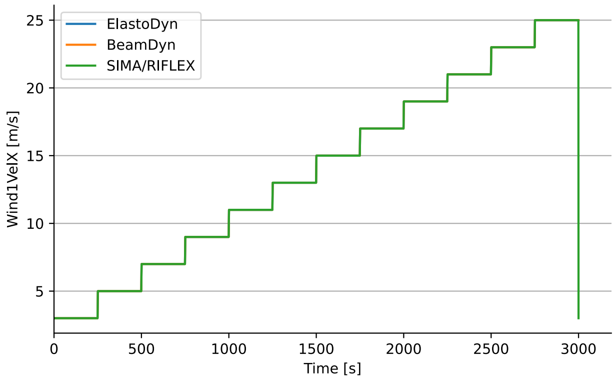
(e) Gen. Power

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

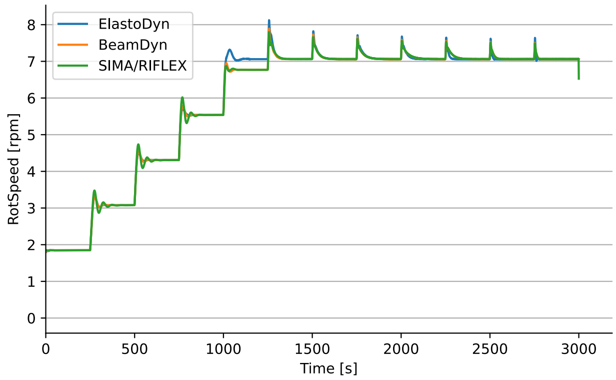
5 Stepped Wind Response

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:

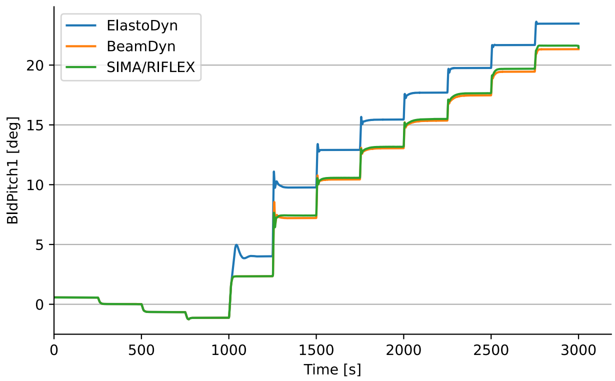
- Aerodynamic modelling: In the reference OpenFAST AeroDyn module input files of the IEA 15MW turbine, the wake/induction model is set to the steady *BEMT* model by default, while RIFLEX uses an implementation more similar to the *DBEMT* option. The OpenFAST input may be modified and revised in a future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



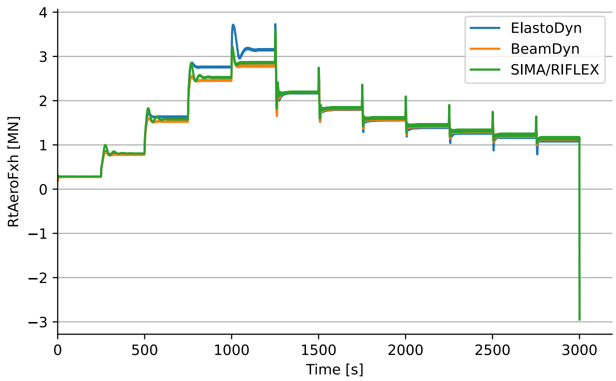
(a) Wind speed



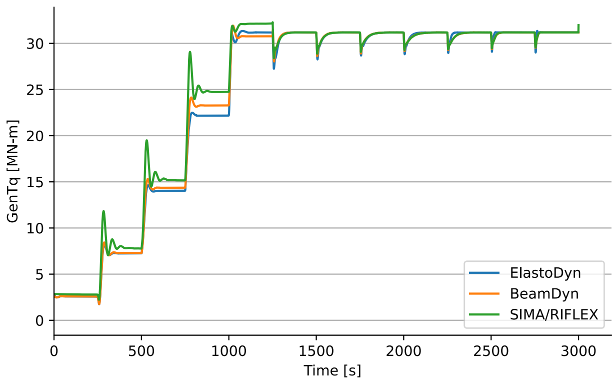
(b) Rotor Speed



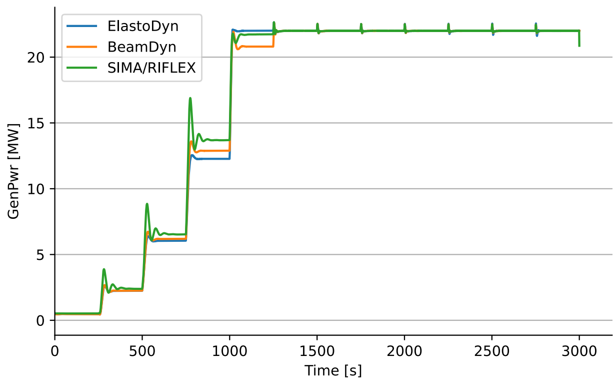
(c) Blade Pitch



(d) Aero. Thrust



(e) Gen. Torque



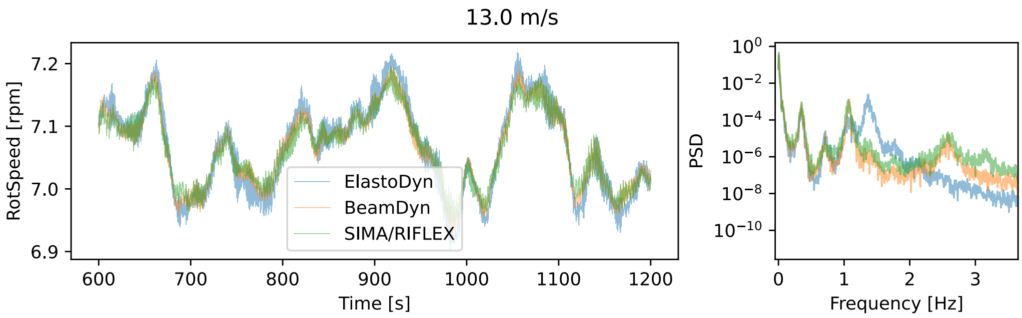
(f) Gen. Power

Figure 2: Response under stepped wind loads

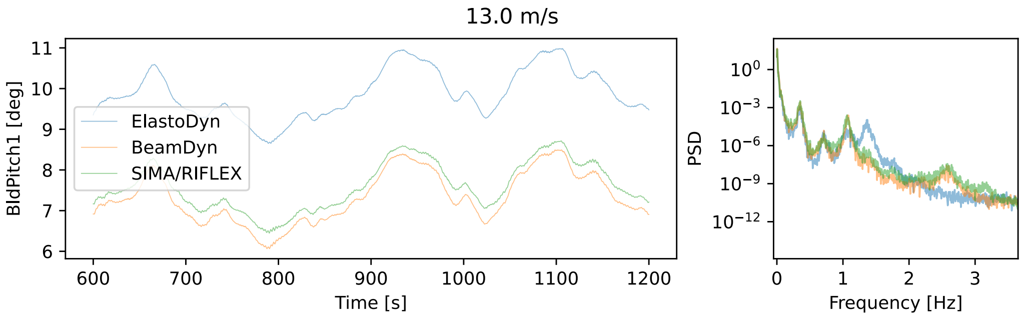
6 Turbulent Wind Response

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. 3 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.

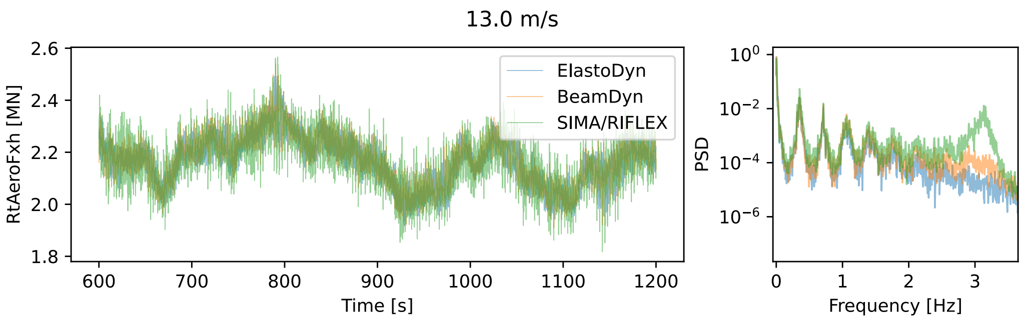
Violin plots are also presented in Figures 4 to 7, showing the distribution of the response. As for the stepped wind response, BeamDyn and SIMA show similar results, with the largest deviations seen at rated wind speed.



(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 $13.0\,\mathrm{m\,s^{-1}}$.

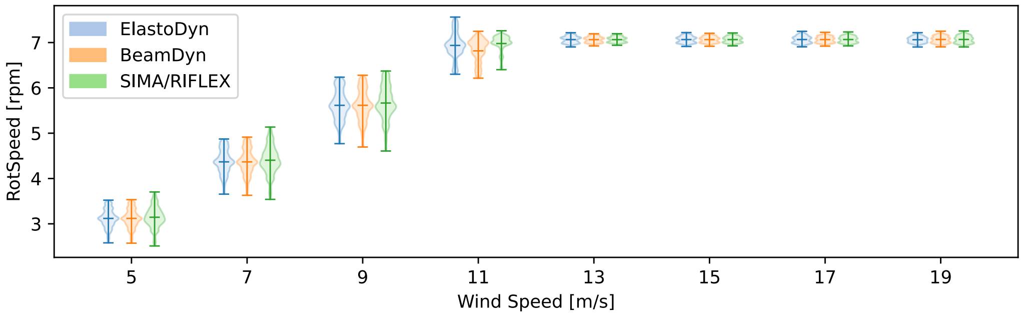


Figure 4: Rotor Speed

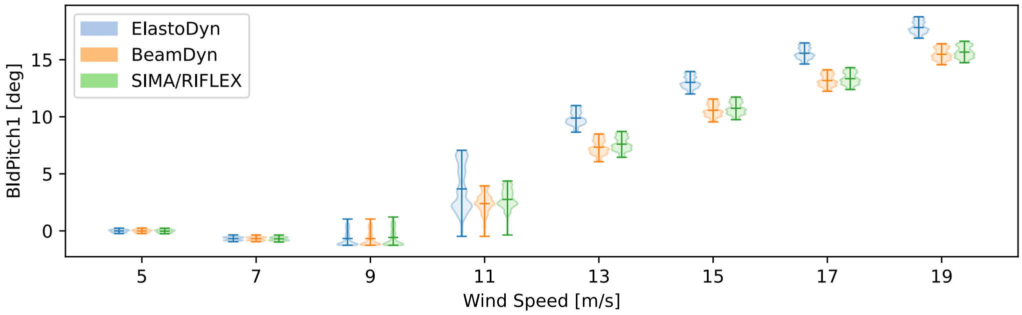


Figure 5: Blade Pitch

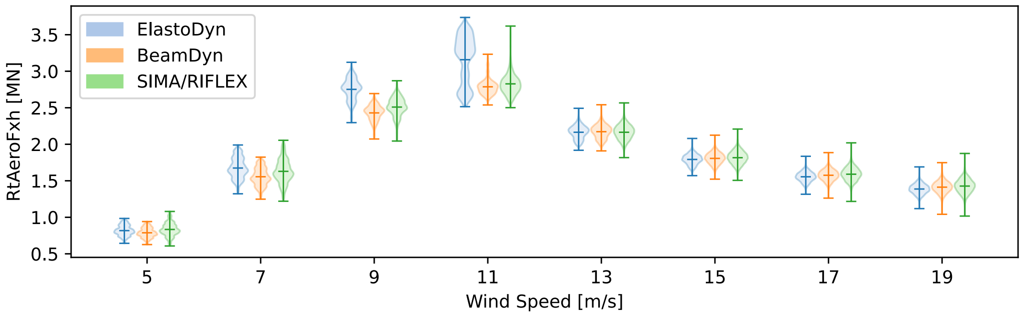


Figure 6: Aero. Thrust

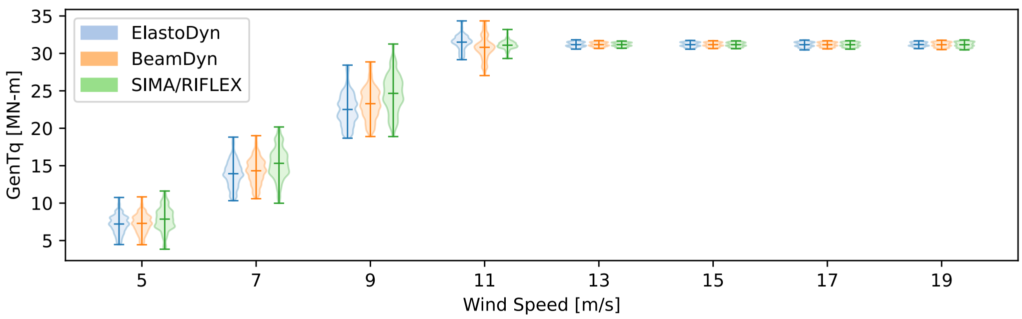


Figure 7: Gen. Torque

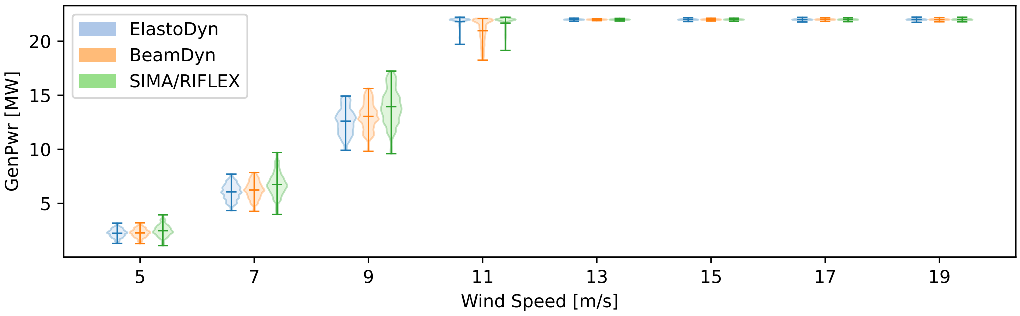


Figure 8: Gen. Power

References

[1] Frederik Zahle et al. *Definition of the IEA Wind 22-Megawatt Offshore Reference Wind Turbine*. Tech. rep. DTU Wind Report E-0243, https://doi.org/10.11581/DTU.00000317. Technical University of Denmark, International Energy Agency, 2024.

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

[3] *IEAWindSystems/IEA-22-280-RWT*. 13th May 2024. URL: https://github.com/IEAWindTask37/IEA-15-240-RWT (visited on 13/05/2025).

A Time Series and PSD Plots of Turbulent Wind Reponse

A.1 Mean Wind Speed 5 m/s

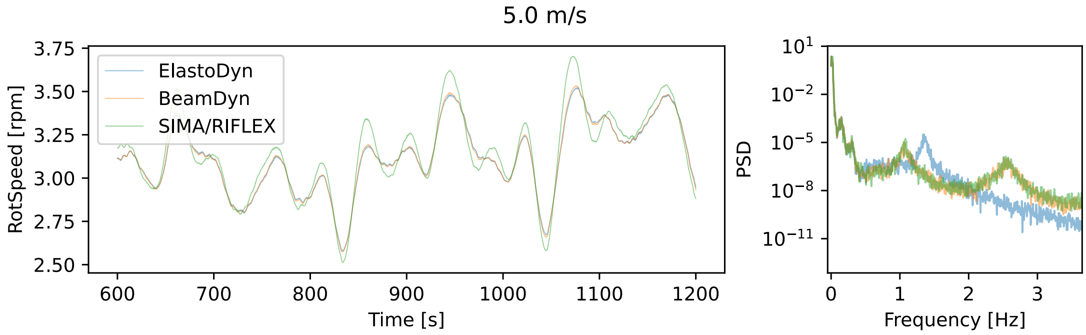


Figure 9: Rotor speed

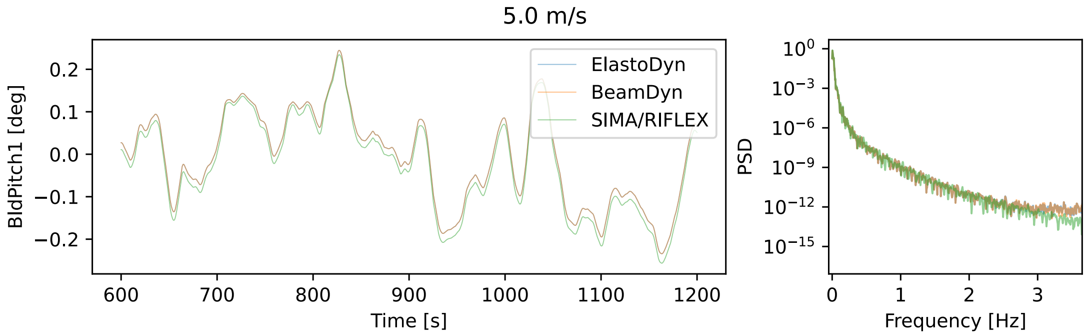


Figure 10: Blade pitch

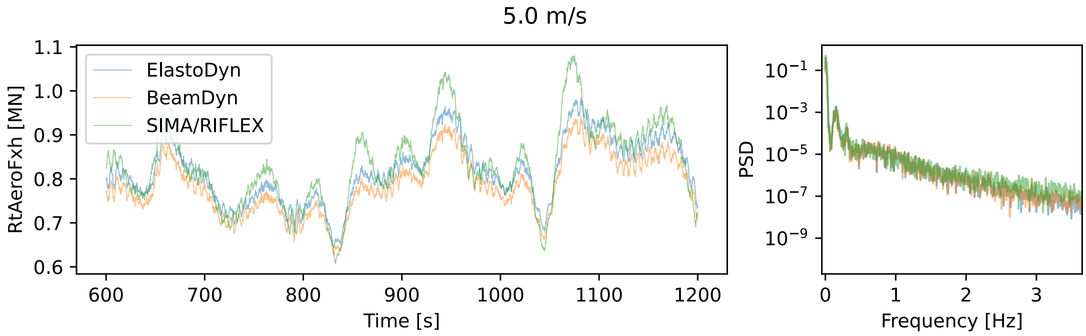


Figure 11: Aero. thrust

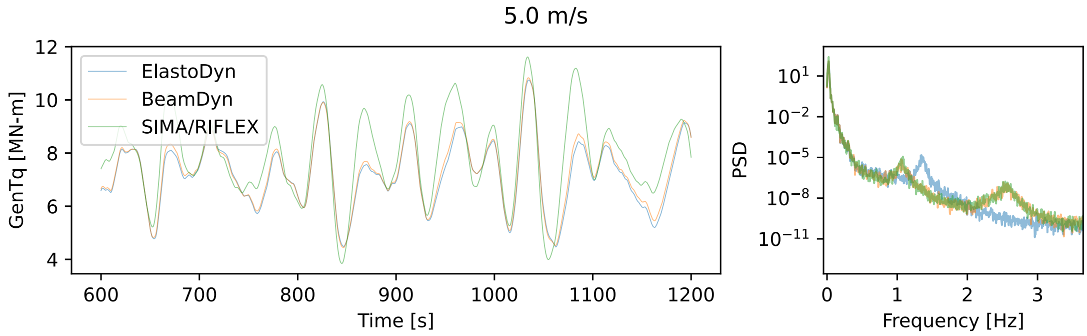


Figure 12: Generator torque

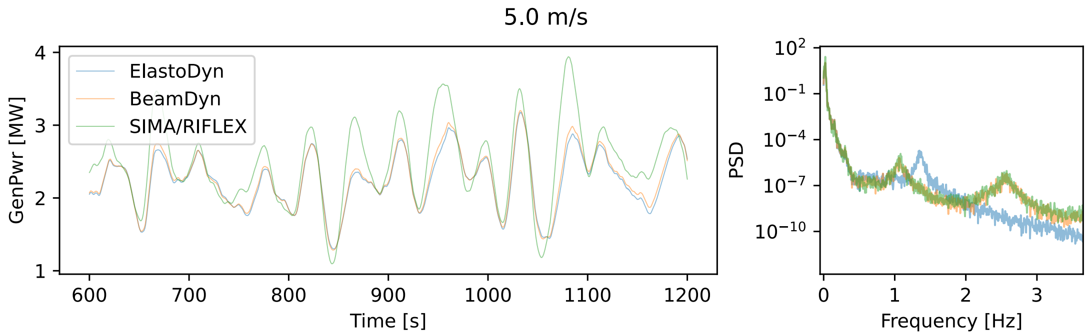


Figure 13: Generator power

A.2 Mean Wind Speed 7 m/s

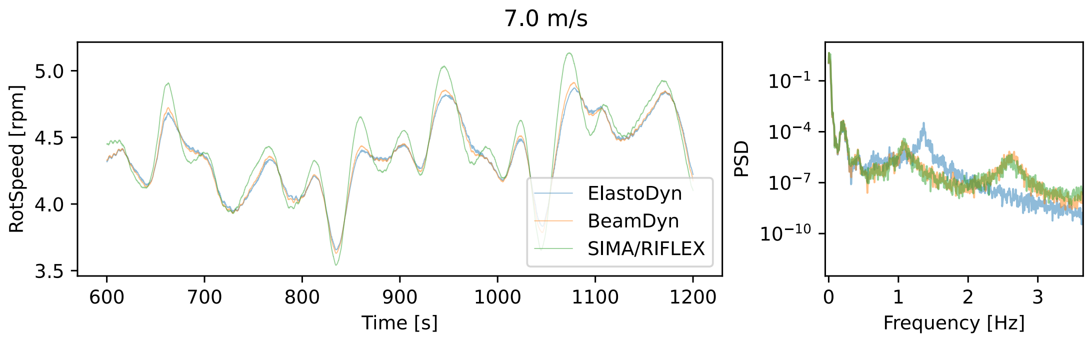


Figure 14: Rotor speed

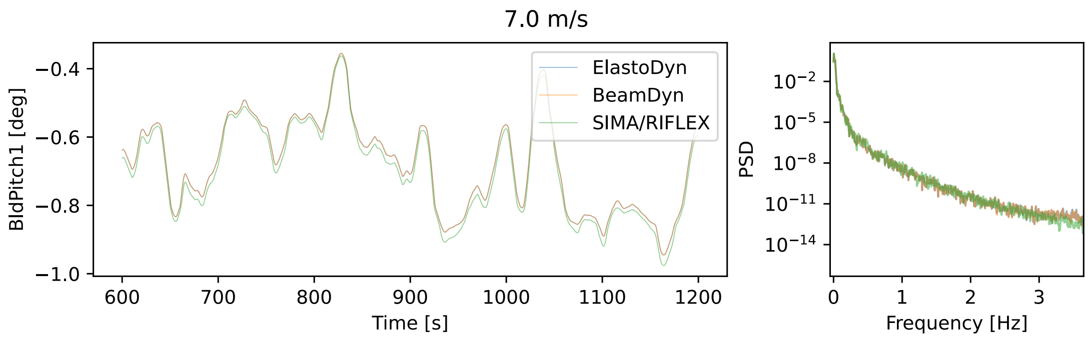


Figure 15: Blade pitch

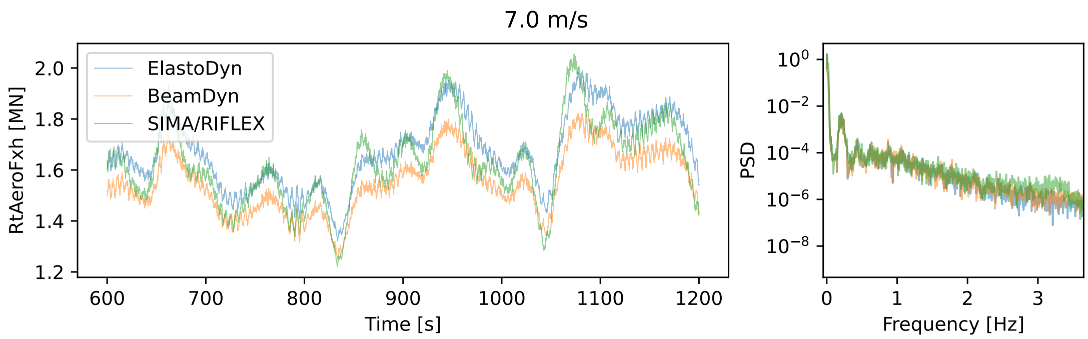


Figure 16: Aero. thrust

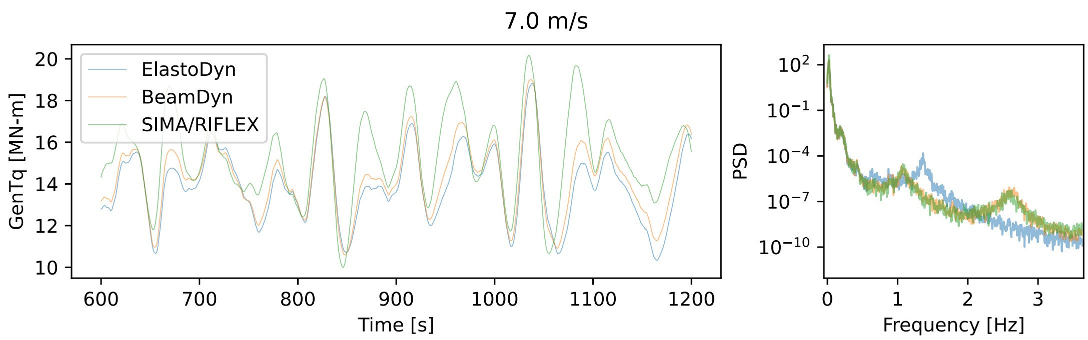


Figure 17: Generator torque

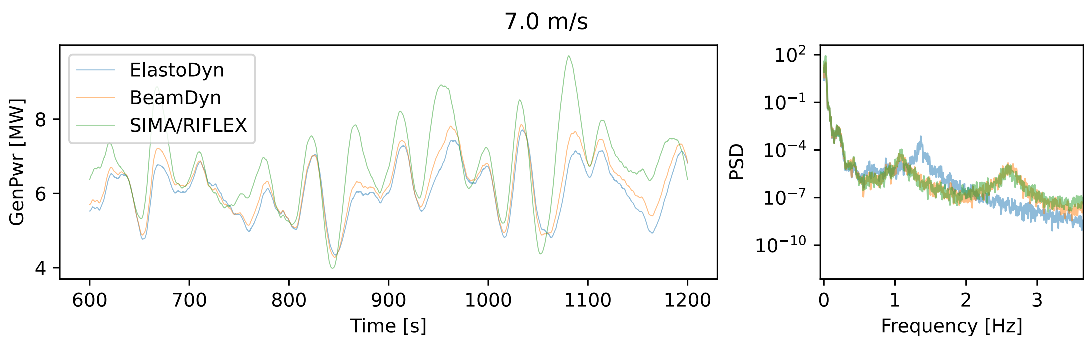


Figure 18: Generator power

A.3 Mean Wind Speed 9 m/s

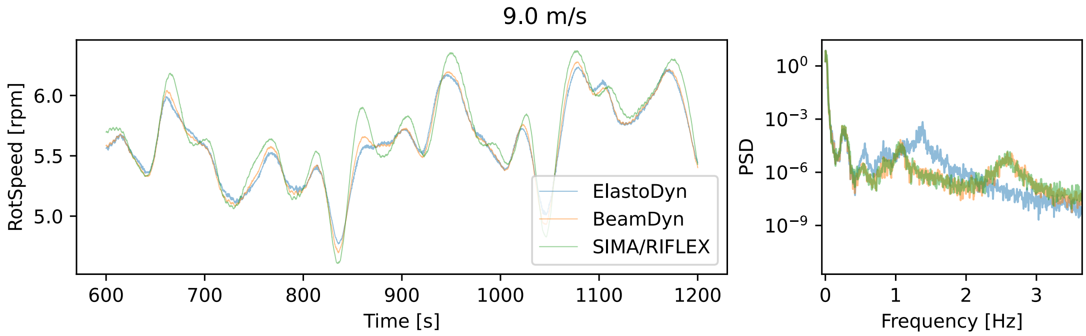


Figure 19: Rotor speed

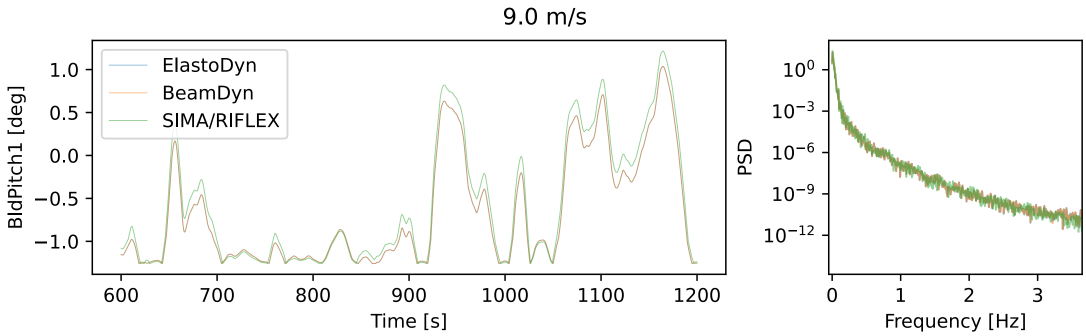


Figure 20: Blade pitch

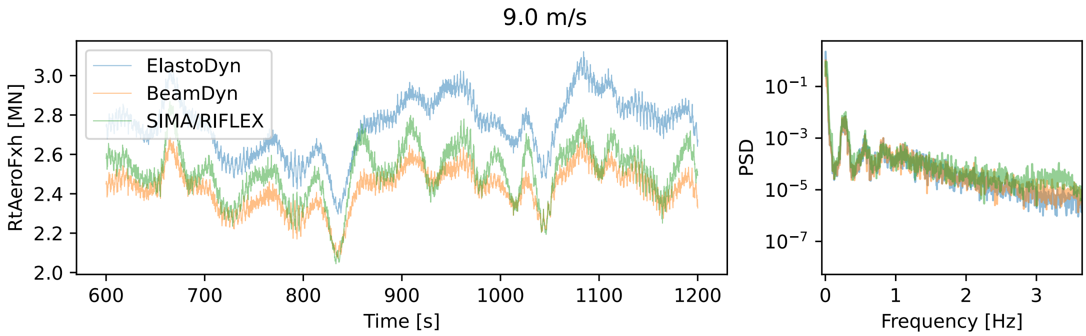


Figure 21: Aero. thrust

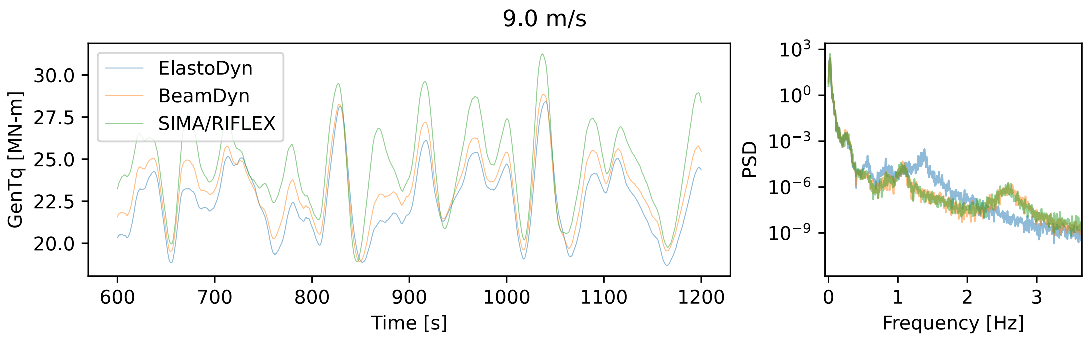


Figure 22: Generator torque

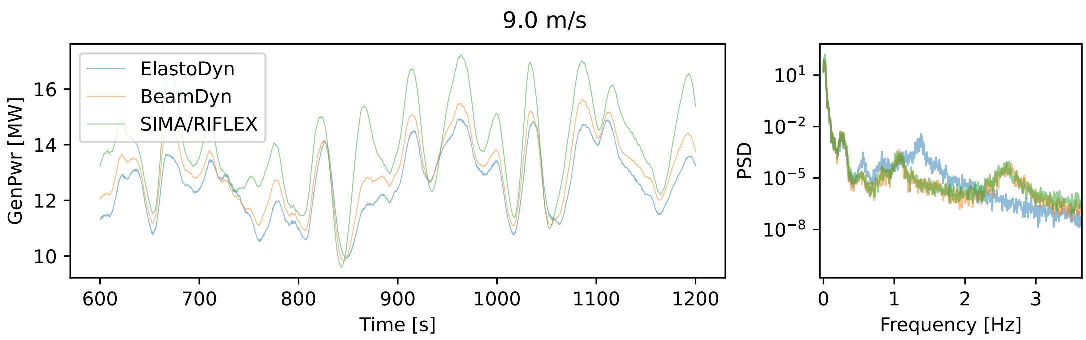


Figure 23: Generator power

A.4 Mean Wind Speed 11 m/s

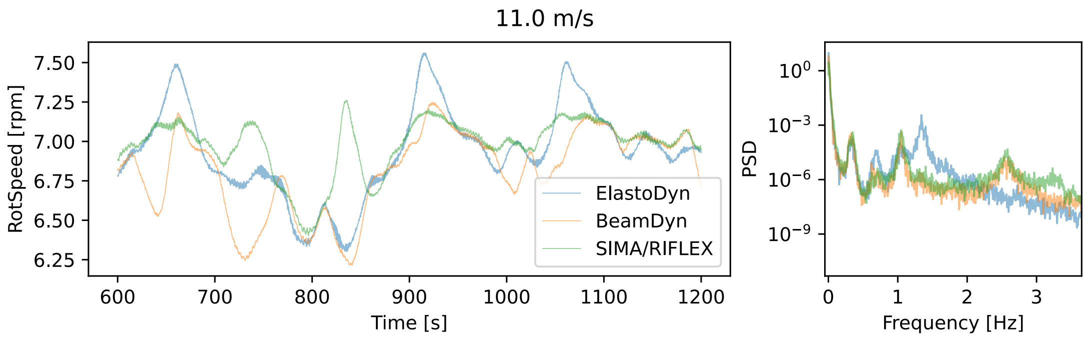


Figure 24: Rotor speed

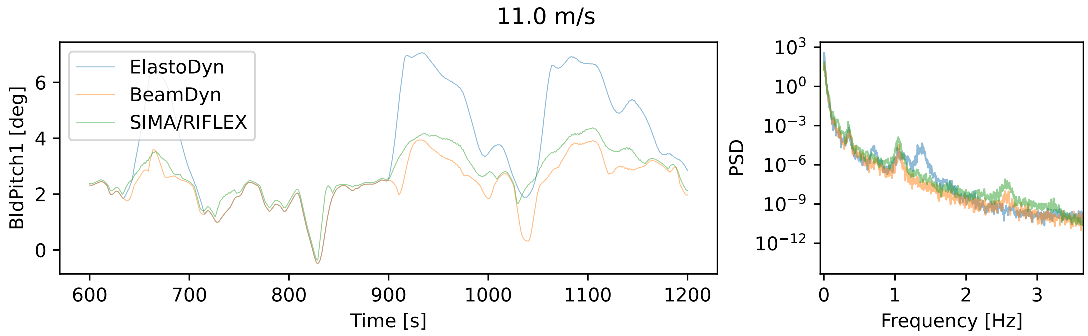


Figure 25: Blade pitch

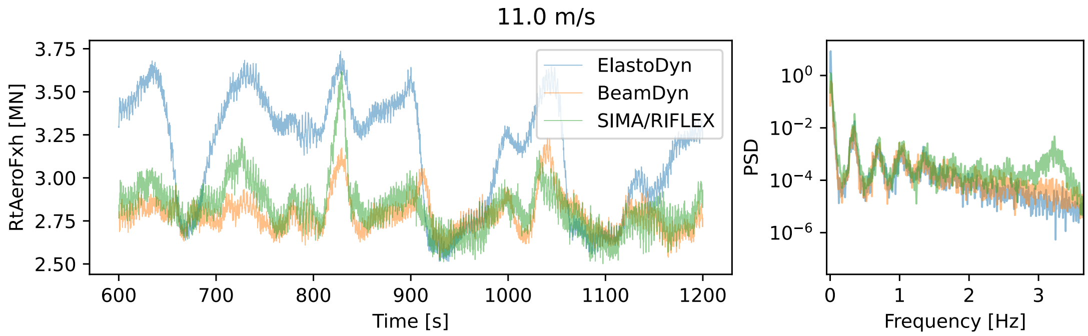


Figure 26: Aero. thrust

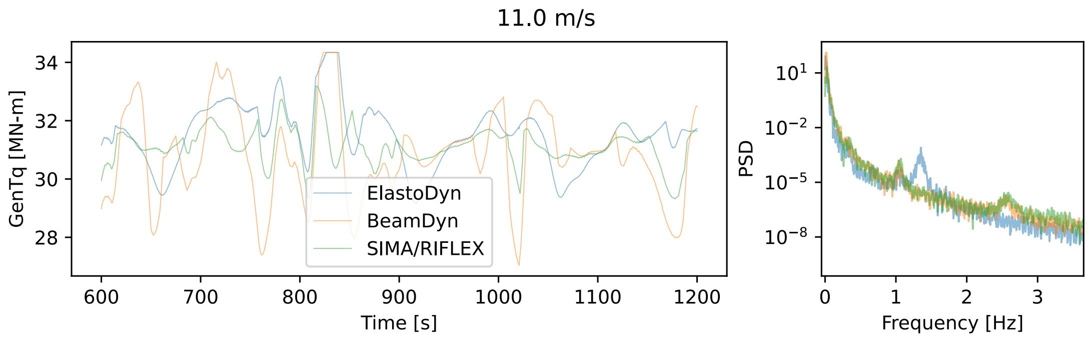


Figure 27: Generator torque

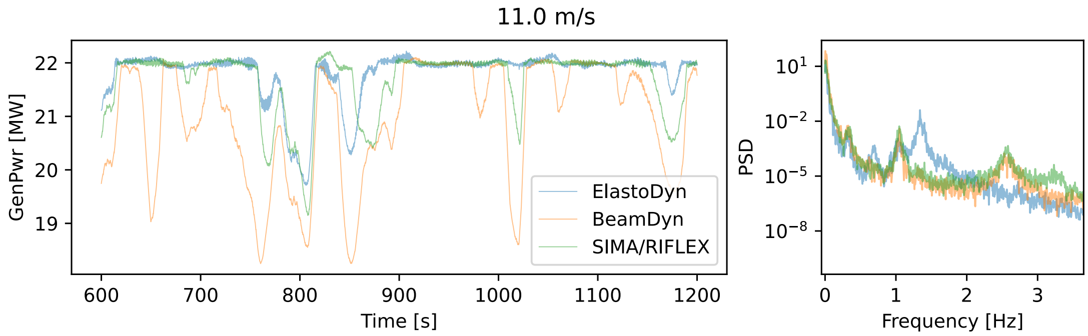


Figure 28: Generator power

A.5 Mean Wind Speed 13 m/s

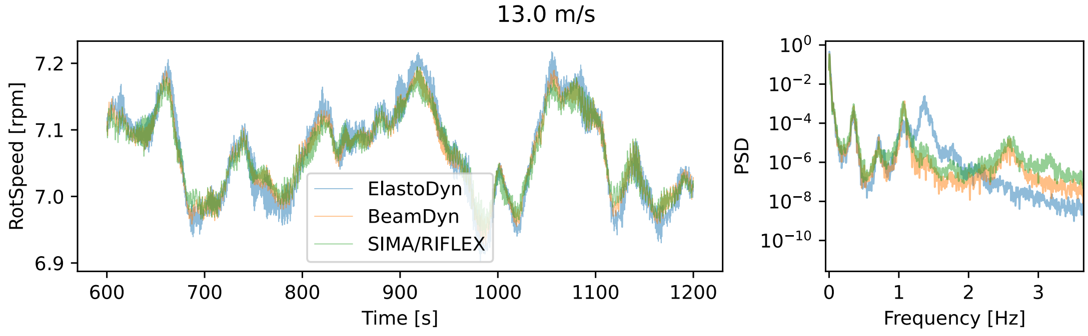


Figure 29: Rotor speed

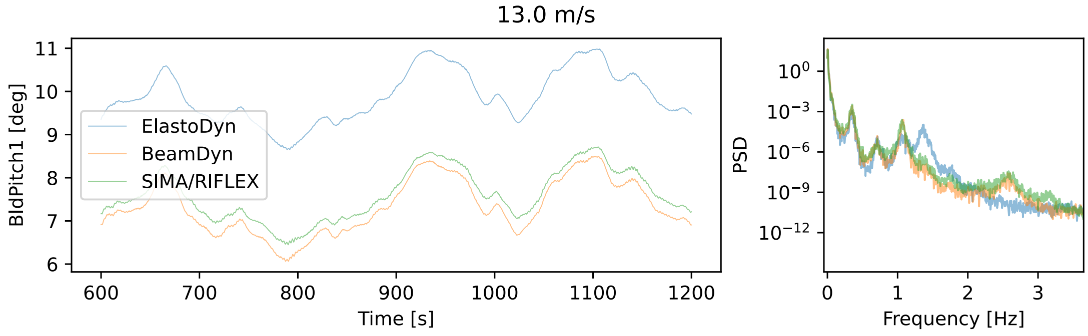


Figure 30: Blade pitch

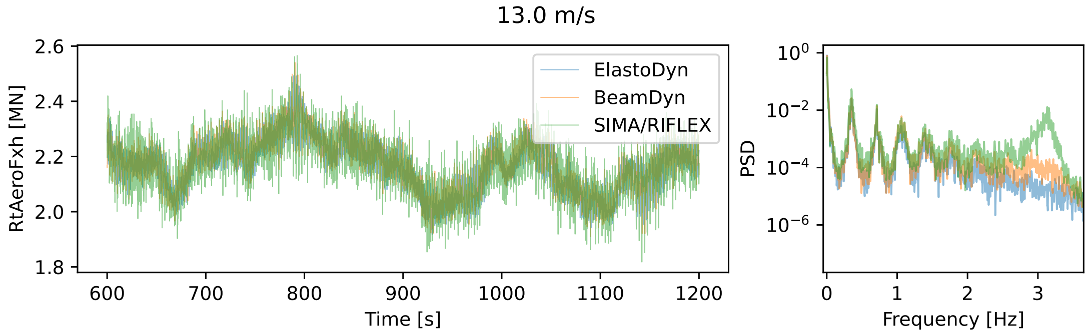


Figure 31: Aero. thrust

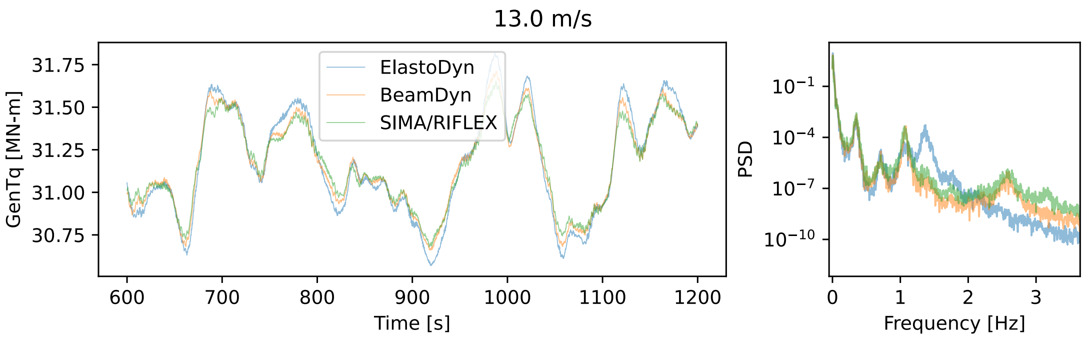


Figure 32: Generator torque

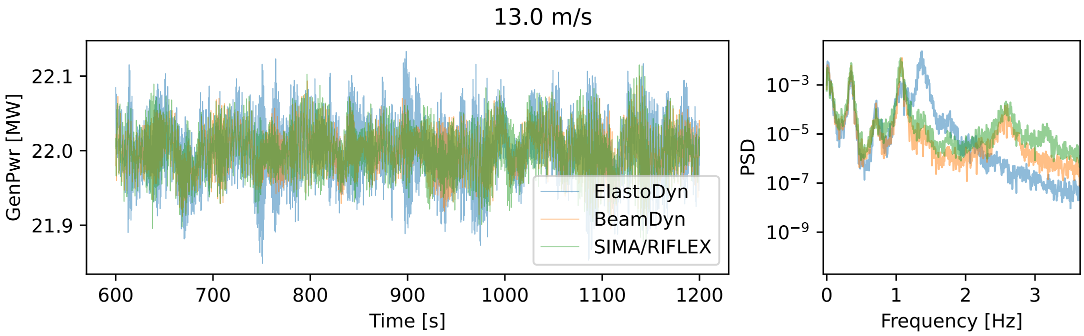


Figure 33: Generator power

A.6 Mean Wind Speed 15 m/s

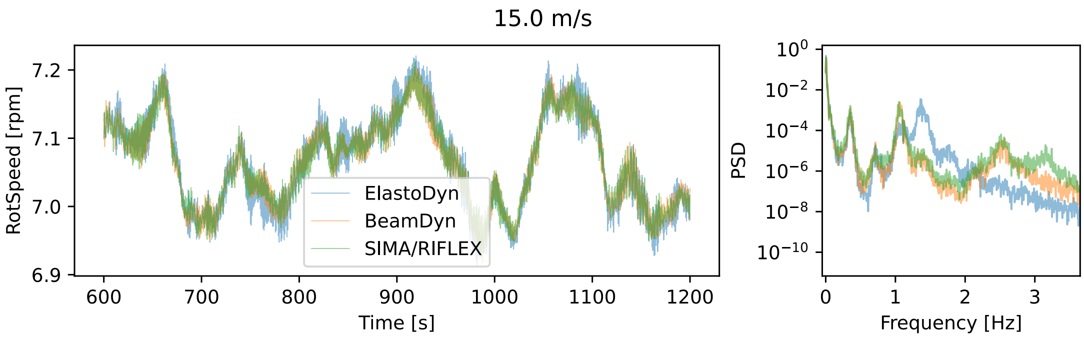


Figure 34: Rotor speed

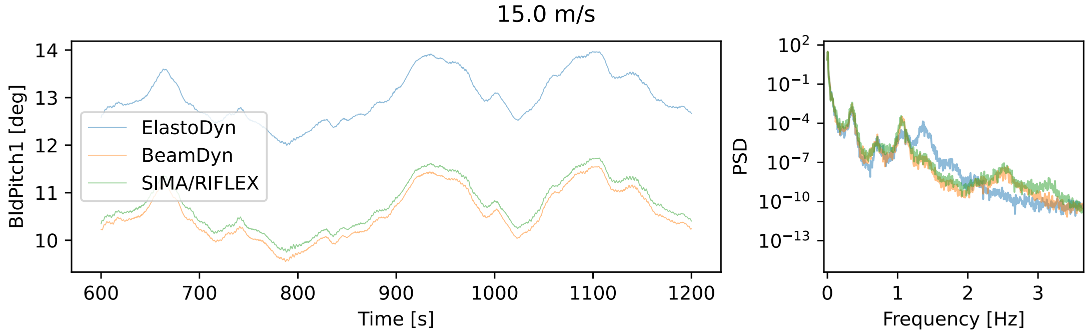


Figure 35: Blade pitch

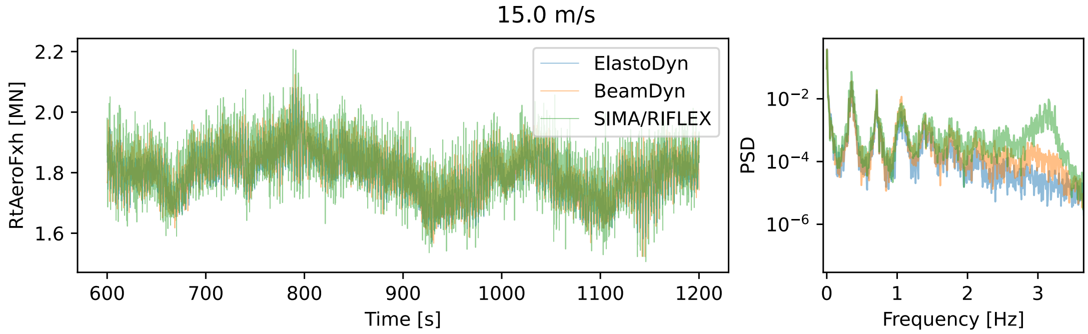


Figure 36: Aero. thrust

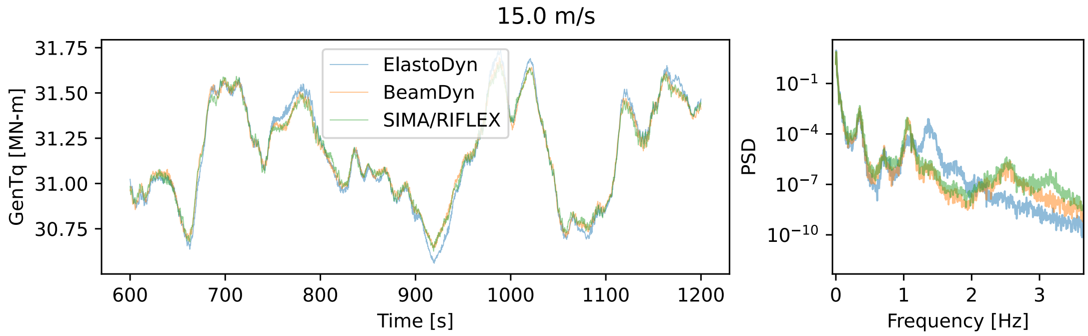


Figure 37: Generator torque

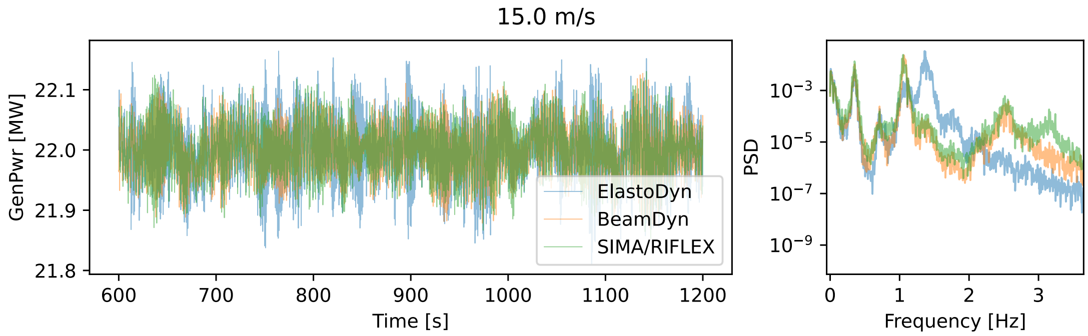


Figure 38: Generator power

A.7 Mean Wind Speed 17 m/s

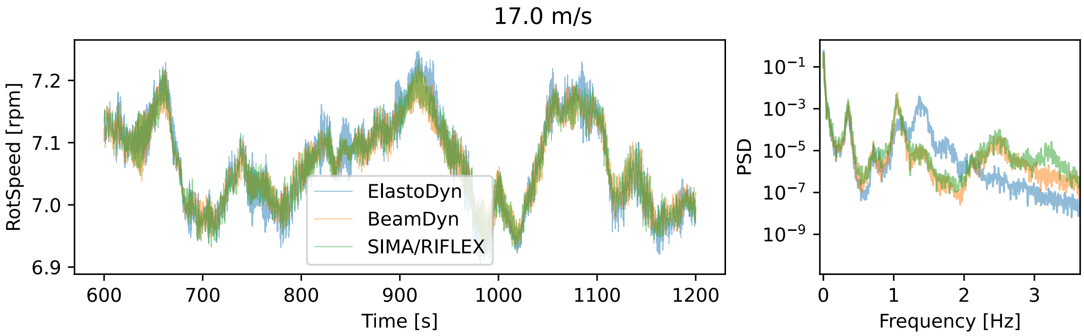


Figure 39: Rotor speed

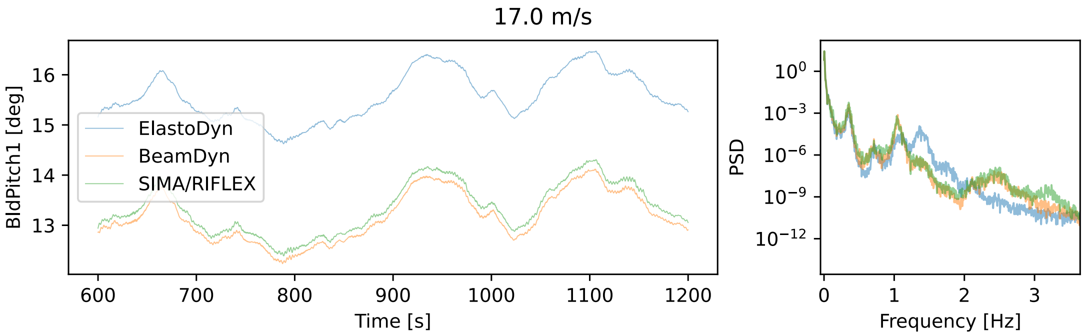


Figure 40: Blade pitch

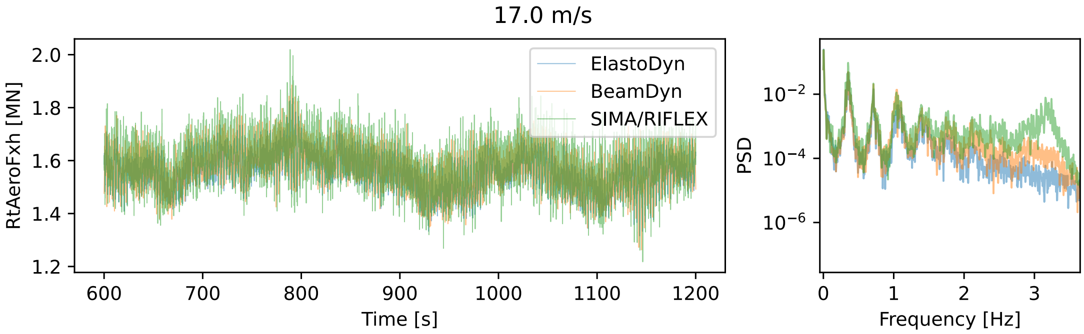


Figure 41: Aero. thrust

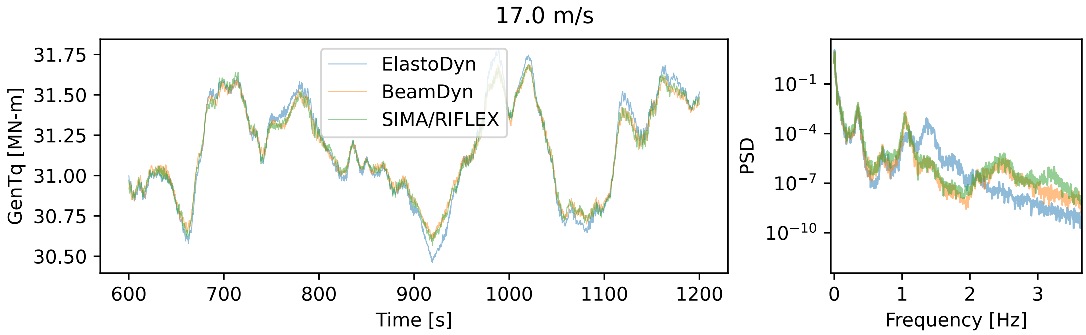


Figure 42: Generator torque

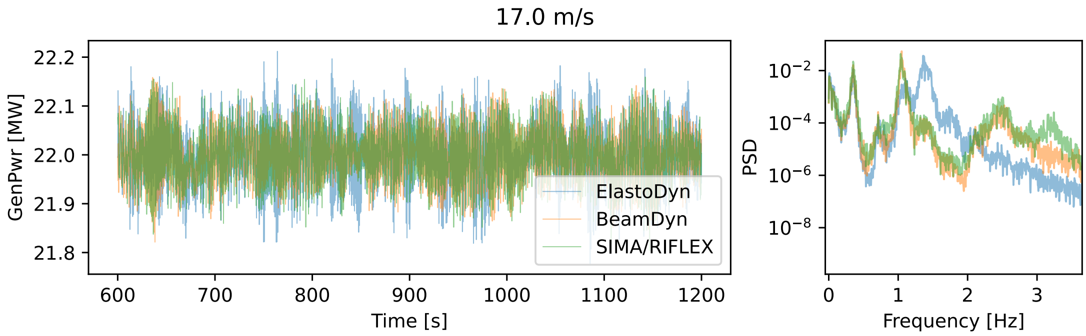


Figure 43: Generator power

A.8 Mean Wind Speed 19 m/s

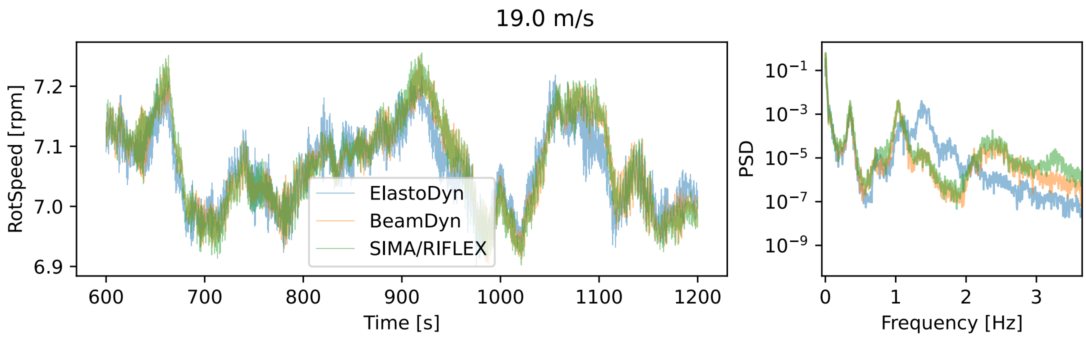


Figure 44: Rotor speed

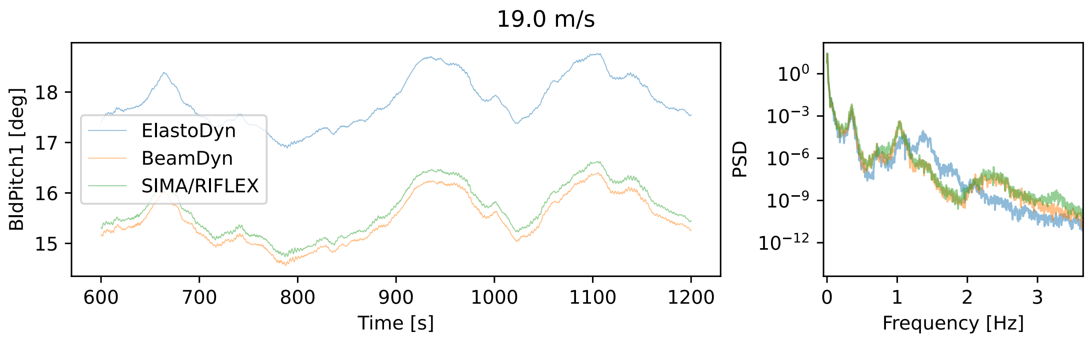


Figure 45: Blade pitch

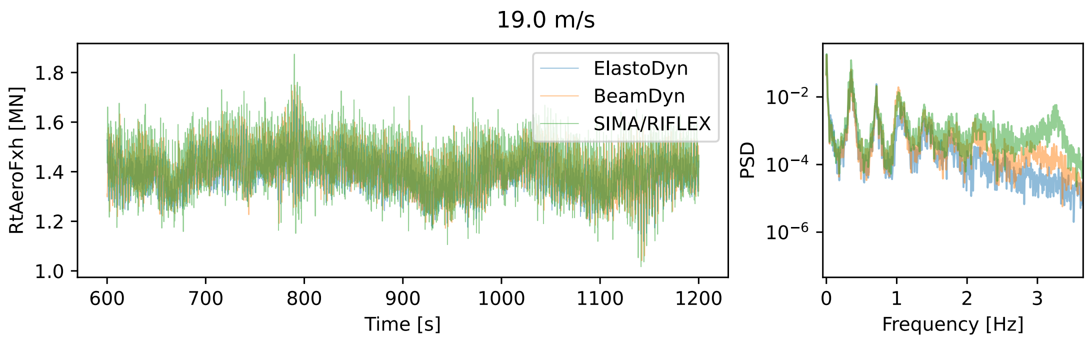


Figure 46: Aero. thrust

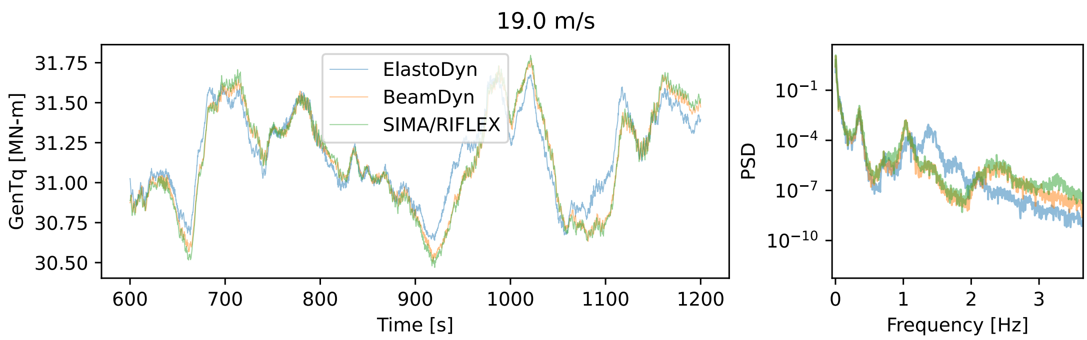


Figure 47: Generator torque

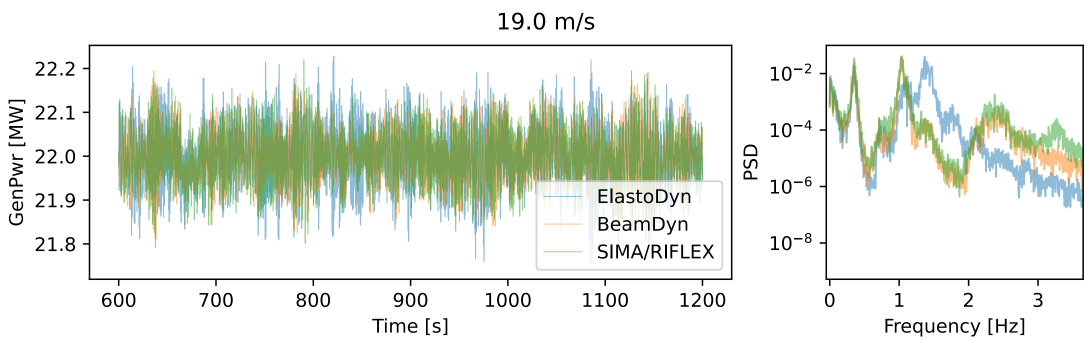


Figure 48: Generator power