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WIND TURBINE LOAD SIMULATIONS USING TWO DIFFERENT SERVO-HYDRO-AEROELASTIC SOFTWARE CODES

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Abstract. *In this paper, the results of the comparison between FAST and ASHES software used to perform servo-hydro-aeroelastic simulations are presented. The focus of this paper has been the assessment of wind turbine modeling codes through code-to-code comparisons. The lack of similarities between the results will be shown and the sources of the differences will be discussed. The aerodynamic load calculation in the form of internal cross-section forces along the blades and the tower will be investigated. Moreover, the dynamic response of the structure is obtained in the simulation result. Furthermore, attention is given to the generator model, outputs and the pitch control system. The comparison will be done based on IEC 61400-1 design load cases for operation and idling conditions. Finally, recommendations concerning the modeling of the wind turbine with the servo-hydro-aeroelastic simulation tools will be given.*

1 INTRODUCTION

Nowadays, the analysis of different types of wind turbines, including onshore, offshore, and floating with different supporting structures relies on aero-hydro-servo-elastic simulation codes. These coupled simulation tools are based on time-domain analysis and take into account different environmental forces and conditions. Furthermore, the entire structural assembly of the turbine, including its control system are coupled with the loads to bring the real time solution for wind turbine simulations. To make sure that the simulations results from different tools are accurate and precise enough, verification and validation of the codes are required which complexity of the models make it more difficult. Due to high cost of measurement data and also lack of open source data the validation of all these simulation tools are not possible. Therefore, there is the need to perform code- to-code comparisons (verification) instead. There are few international code comparison projects for offshore wind turbine, namely OC3[1] and OC4[2] which focused on different offshore supporting structures and semisubmersible floating structures. Different academic and industrial research centers participated in OC3 and OC4 code comparison including FAST [3] and ASHES [4].

State of the art of the most common aero-hydro-servo-elastic simulation codes are summarized in Table 1.

Code	Aerodynamics	Hydrodynamics	Control	Structural
ASHES	BEM + DS	Airy^{str} + ME	Internal Control System	FEM
FAST	BEM or GDW + DS	Airy^{str} or UD + ME	DLL or UD or SM	Support structure: FEM, Airystr or UD + ME Turbine: FEM^{p} + Modal/MBS
HAWC2	BEM or GDW + DS	Airy^{str} or Stream or UD + ME	DLL or UD or SM	MBS/FEM

Table 1: The most common simulation tools state of the art

Airy^{str} – Airy yheory with streaming method
BEM – Blade Element Momentum Theory
DLL – External dynaic link library
DS – Dynamic Stall Implementation
FEM – Finite element method
FEM^{p} – Finite element method for pre-processing only
GDW – Generalized Dynamic Wake Theory
MBS – Multibody dynamics formulation
ME – Morrison Formulation
Modal – Modal reduced system
SM – Interface to Simulink with Matlab
Stream – Dean's system function
UD – User defined subroutine

In this paper, a set of design load cases is investigated and compared between two software codes, ASHES and FAST. ASHES software is a new developed tool and FAST is an open source and more advanced software validated with several measurement data.

2 GENERAL SPECIFICATIONS

2.1 Wind Turbine Properties

In this study, the NREL 5 MW wind turbine is modeled in both software. The power electronics, generator, blades and other parts properties are NREL baseline turbine default [5] and only the controller are different in each software. The NREL 5MW wind turbine gross properties is mentioned in Table 2.

Properties	Value
Rating	5MW
Rotor Orientation, Configuration	Upwind, 3 Blades
Control	Variable Speed, Collective Pitch
Drive Train	High Speed, Multiple-stage Gearbox
Rotor, Hub Diameter	126m, 3m
Cut-In, Rated, Cut-Out Wind Speed	3 m/s, 11.4m/s, 25m/s
Cut-In, Rated Rotor Speed	6.9 rpm, 12.1rpm
Rated Tip Speed	80m/s
Overhang, Shaft Tilt, Pre-cone	5m, 5˚, 2.5˚
Rotor Mass, Nacelle Mass	110,000 Kg, 240,000 Kg

Table 2: NREL 5MW Gross Properties

Error! Reference source not found. shows the coordinate system and the loads definition. The x axis pointing in the nominal (0˚) wind flow direction, y axis pointing to the left perpendicular to x axis and z axis pointing up from the center which means the compression is consider as a negative force.

Figure 1: Tower-base coordinate system [3]

The tubular tower for the NREL 5 MW turbine has the base diameter of 6 m, the base thickness of 0.027 m, top diameter of 3.87 m and the top thickness of 0.019 m. The mechanical properties of the tower are defined as the young's modulus equals to 210 GPa, the shear modulus of 80.8 GPa, and the effective density of 8500 kg/m^3 which is considered including are added mass such as welding.

2.2 Design Load Cases

The load cases for the design and certification of the onshore wind turbine structure were discussed completely in IEC 61400-1 standard[6]. The approach in this research is based on the IEC 61400 recommendations, as will be described in detail in the following sections. As the wind turbine is onshore wind turbine and it is a tall structure, the A (II) class is considered in this study. The turbulence intensity is 0.16 and the reference wind speed (V_{ref}) is equal to 42.5 m/s. The most crucial load cases for normal operational condition and parked were selected and listed in Table 3.

Design Situation	**DLC**	**Wind Condition**
Power production	1.1	NTM $V_{in}<V_{hub}<V_{out}$
Parked (Standing or Idling)	6.1	EWM 50-year recurrence period

Table 3 : The load case definition

However, the 11 m/s constant wind speed was also modeled beside the main design load cases in order to compare the rotor and the generator responses in both software.

In power production the pitch controller is on and the pitch angle is controlled if the wind speed exceeds from the rated wind speed. In DLC 6.1, the pitch controller is off and the pitch angle is assumed to 90° to simulate the parked wind turbine. To model the wind models for both software, the TurbSim [7] code is used and the same input file is used for the verification.

3 RESULTS

In this section, the wind turbine rotor and generator response is presented for constant wind speed and the main force and moments at the hub height of the turbine and the pitch controller performance are investigated for two standard design load cases.

3.1 Rotor and Generator Response

Figure 2 shows the rotor and the generator speed. As it can be seen, great agreement can be observed between both codes with less 1% of the error. Same interpretation can be given for the for the power and torque in both codes

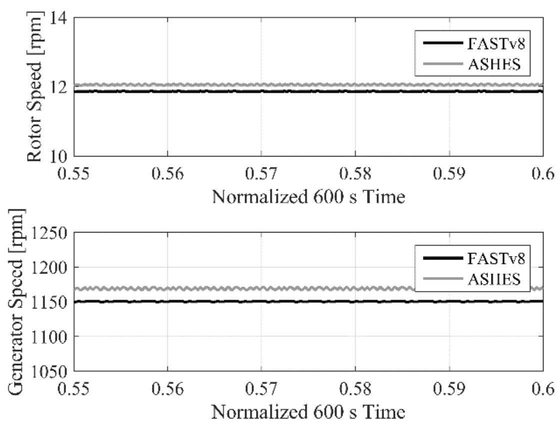


Figure 2 : The rotor and the generator speed

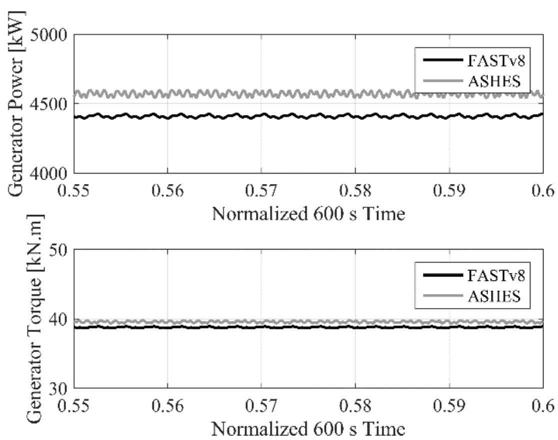


Figure 3 : The torque and power output

A window of the rotor power signal is shown in Figure 5 when the tower shadow effect is taken into account. The peak which is illustrated with a red sign is due to tower shadow effect and it is clearly captured. The difference between the fluctuations comes from different controller for the generator, the boundary condition assumptions, and the different integration methods.

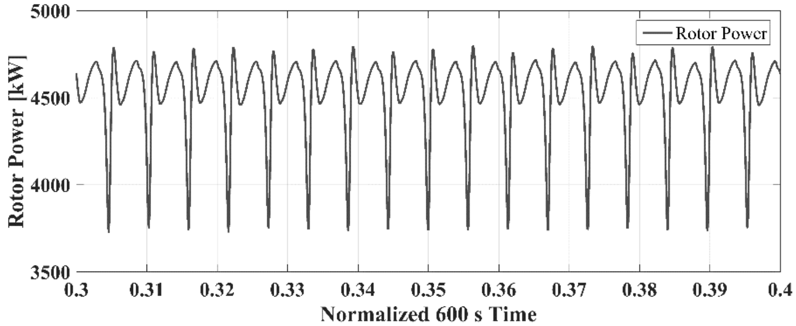
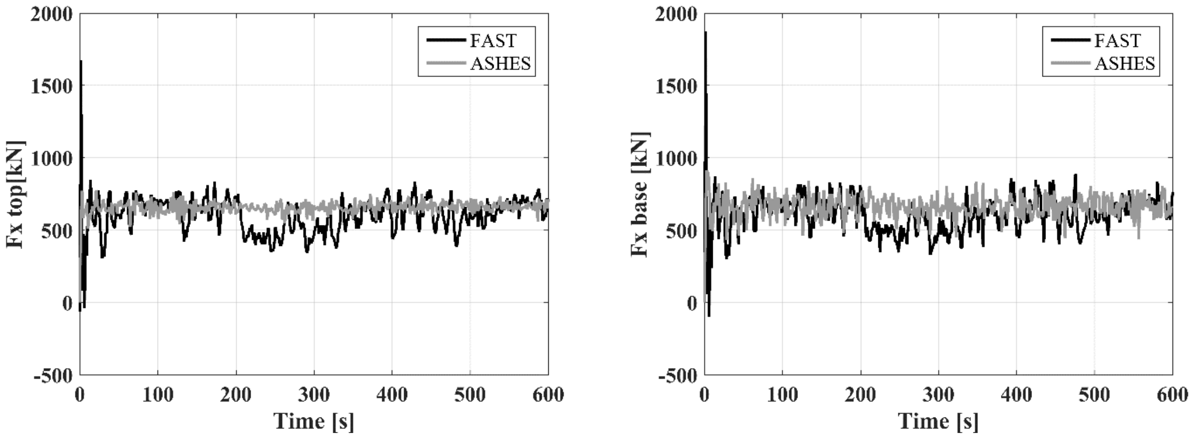


Figure 4 : The generator power fluctuation

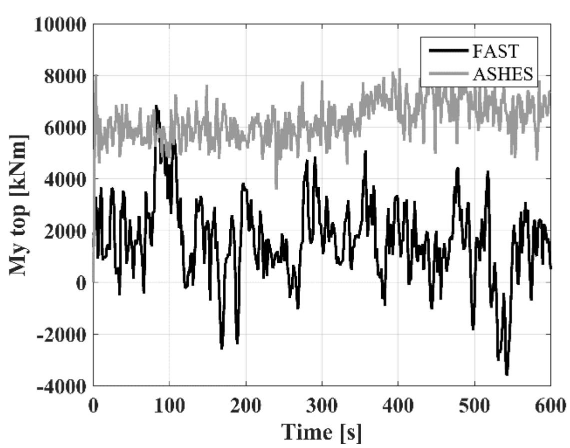
3.2 DLC 1.1

The DLC 1.1 uses normal turbulent wind model. Two, 12 m/s and 25 m/s, wind speeds are crucial to be investigated as they are respectively the highest wind speed before the pitch controller starts and the highest operational wind speed. Figure 5 shows the force and moment comparison for 12 m/s for the tower top section.

As it can be seen, the force on x-axis in ASHES has great precision on the top and the base of the tubular tower according to FAST. It is interesting to see that the moment about the strong axis in the fast has very big fluctuation while the ASHES has almost constant deviation around a mean value. However, the moment at the base of the tubular tower which is created by nonlinear force integration along the tower, are in great agreement in both software. In Figure 5(e) the axial force can be great example for the difference of the boundary conditions assumptions. ASHES considers the initial condition of zero and FAST considers the mass of rotor nacelle assembly as the initial condition for solving the finite element model.



(a) (b)



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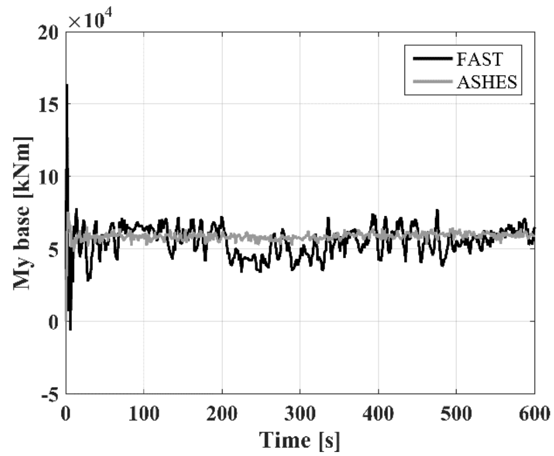

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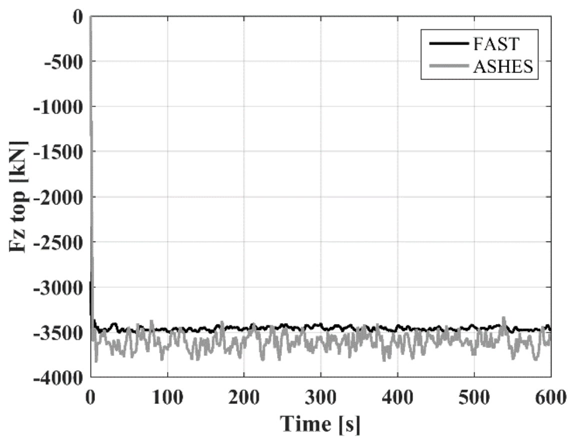
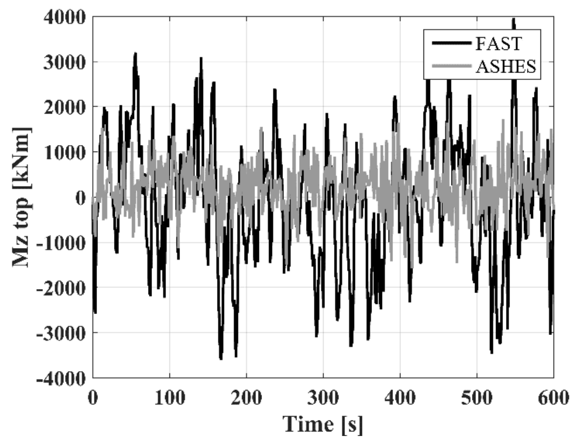


(e)



(f)

Figure 5 : DLC 1.1 comparison (a) Fx force on top,(b)base of tower, (c) My moment on top and (d) base of tower, (e) axial force on top of tower, (f) the torque on the yaw bearing of tower

3.3 DLC 6.1

The DLC 6.1 is the parked or idling wind turbine in extreme wind condition. It uses extreme wind model regarding the reference wind speed of 42.5 for the A (II) wind turbine class. The controller set the pitch angle to 90˚ which cause the deceleration of the rotor speed. Moreover, the generator reduces the rotor speed to zero by applying external hydraulic brakes or generator self-brake. Figure 6 shows the force and moment comparison for 12 m/s for the tower top section.

As it can be seen, all the forces and moments are in strong agreement. The point which is obvious in the figures is that a peak happens around 450 second and both codes reacts to the peaks, however, due to time scale difference there is a lag between the ASHES and FAST. In DLC 6.1 as the rotor blade speed is zero and there is no pitch angle variation, the nonlinearities are much less and thereby, the results are more stable and comparable.

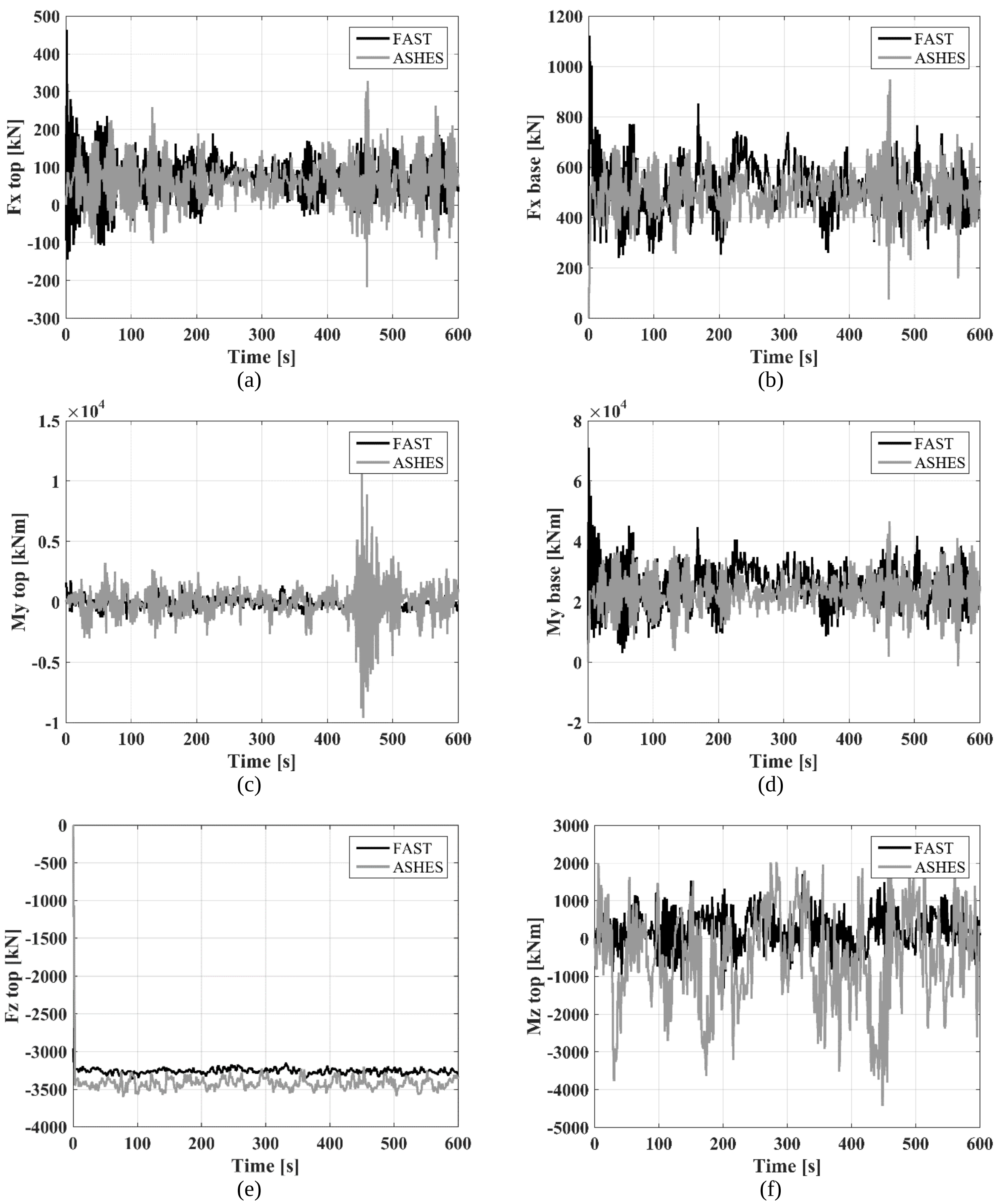


Figure 6 : DLC 6.1 comparison (a) Fx force on top and (b) base of tower, (c) My moment on top and (d) base of tower, (e) axial force on top of tower, (f) the torque on the yaw bearing of tower

4 CONCLUSIONS

This paper presents the results of the comparison between two different aero-servo-hydro-elastic codes. The analysis is focused on the simulation of the NREL 5 MW onshore wind turbine. A detailed description of the turbine model is provided. A set of deterministic and turbulent load cases of increasing complexity is discussed and simulated. The load cases with deterministic inputs are compared in terms of time-series output, and the stochastic cases are compared in terms of probability density functions, power spectral densities. The exemplary discrepancies between the codes are shown and sources of differences are discussed.

The setup of the wind turbine simulations is a detailed and difficult process, involving multidisciplinary engineering knowledge within the fields of meteorology, structural engineering, statistics, data pre- and post-processing etc. Furthermore, differences in the implemented theories and diverse modeling strategies contributed to the discrepancies in the presented results. In the light of these facts, a very good agreement in the obtained results has been achieved and it can been said that the ASHES as new developing code is very promising and the great advantage is the real-time simulation and the great graphic user interface.

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