Integrated Modelling Platform for Dynamic Performance Assessment of Floating Wind Turbines

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DeepWind'2015, 4-6 February 2015, Trondheim, Norway

Outline

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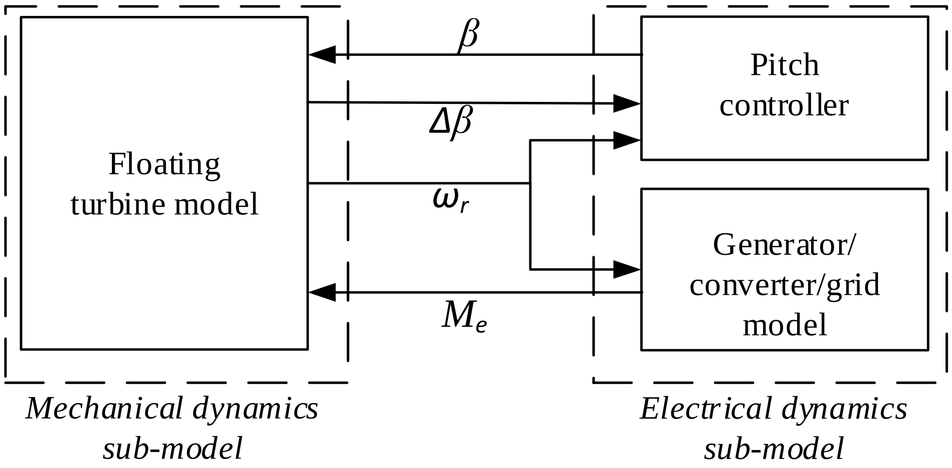
- Implementation of the integrated floating wind turbine model
- Floating wind turbine model
- Electrical model
- Case studies and results
- Conclusion

Introduction

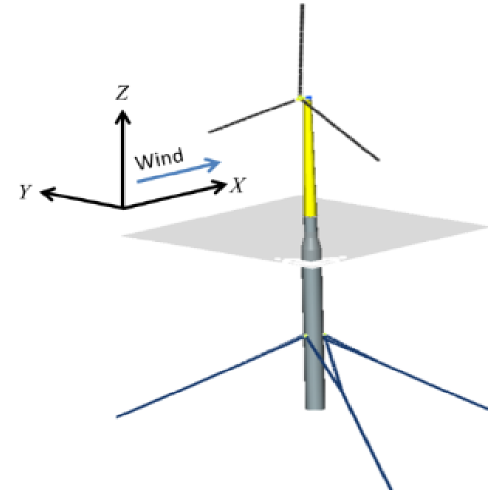
- integrated modelling platform dynamic performance assessment of a floating offshore wind turbine
- state-of-the-art numerical simulation of the hydro-, aero- and structural dynamic behavior of the floating wind turbine
- Sub-models of generator and converter controllers and the power network
- allows analyzing response of floating turbines to grid faults, interactions and potential conflicts between controllers
- study case presented aims to illustrate the applicability of an integrated model to assess response of floating wind turbines and control performance in the event of grid disturbances

Implementation of the integrated wind turbine model



- interface between the electrical system and mechanical sub-models are rotor speed (ω_r), speed of tower movement ($\Delta\beta$), electrical torque (M_e) and pitch angle (β)
- simulation time step of 0.025s
  - It is assumed that the electric time constants ≈ 0, i.e. all the electrical systems and control loops have immediate response.

Floating wind turbine

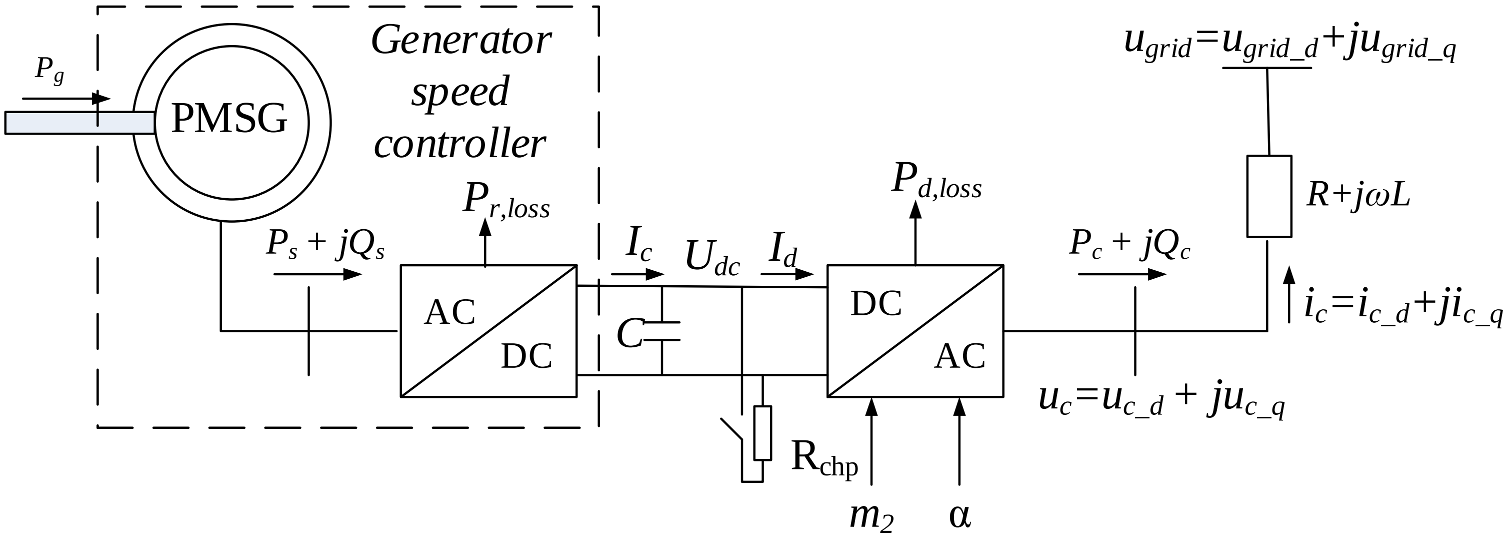


- Wind turbine
  - 5 MW turbine mounted on floating spar-buoy support structure
  - based on the benchmark model developed by the OC3 [1]
- Floating spar
  - equilibrium stick-up position above mean sea-level: 10 m
  - has a slimmer section at the top where the wave loads are largest, and a larger diameter cross section at the lower part
- Mooring lines
  - modeled as structural beam elements with very low bending stiffness
  - Each mooring line consists of 106 beam elements, which are subjected to wave loads and drag forces based on the structural response

Parameter	Value
Rated power	5 MW
Number of rotor blades	3
Rotor diameter	126 m
Tower height	77.6 m
Nacelle mass	240 tons
Blade mass	16.84 t
Hub mass	56.84 t
Tower mass	347.46 t
Shaft axis tilt	5 deg
Blade pre-cone	2.5 deg
Rotor inertia (inc. hub/low speed shaft)	~2.6e7 kgm2

[1] J. M. Jonkman and W. Musial, "Offshore Code Comparison Collaboration (OC3) for IEA Task 23 Offshore Wind Technology and Deployment," NRELDecember 2010 2010.

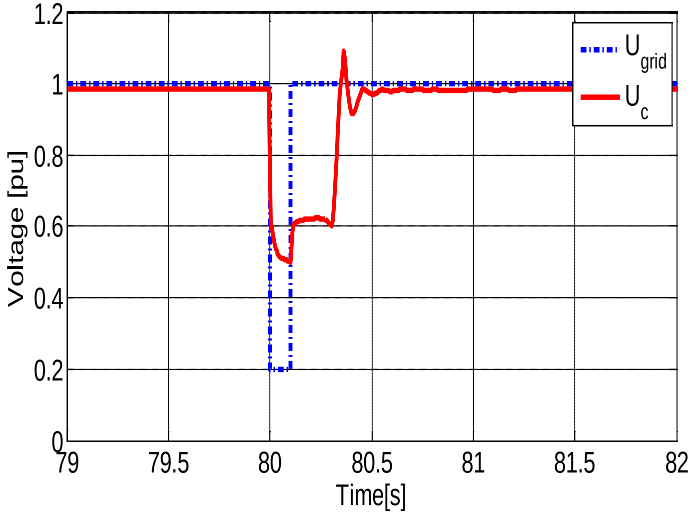
Electrical system sub-model

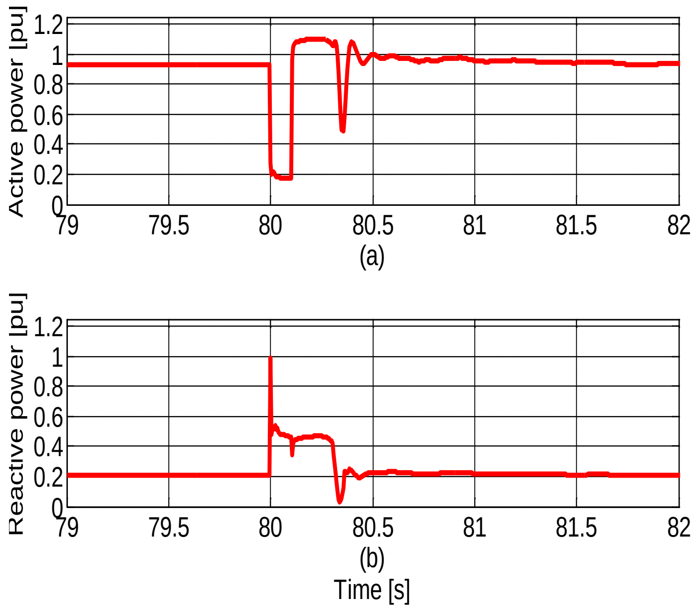


- The generator, generator-side converter and their control are modeled simply as a generator speed controller
- Grid-side converter controller controls DC-link voltage and grid side voltage
- DC link dynamics
- De-loading loop and breaking resistor (chopper) are used for DC voltage control
- Pitch controller and electrical grid

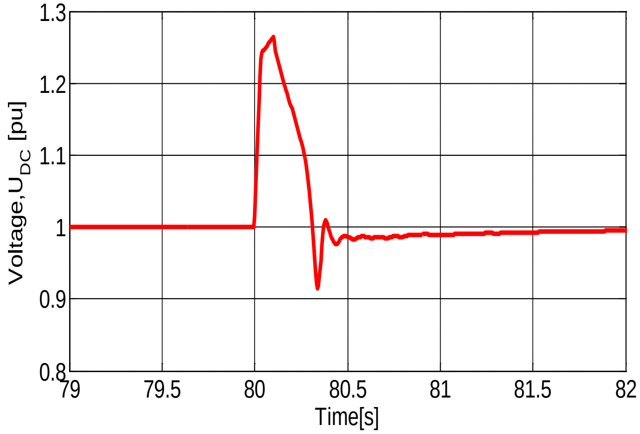
Simulation studies

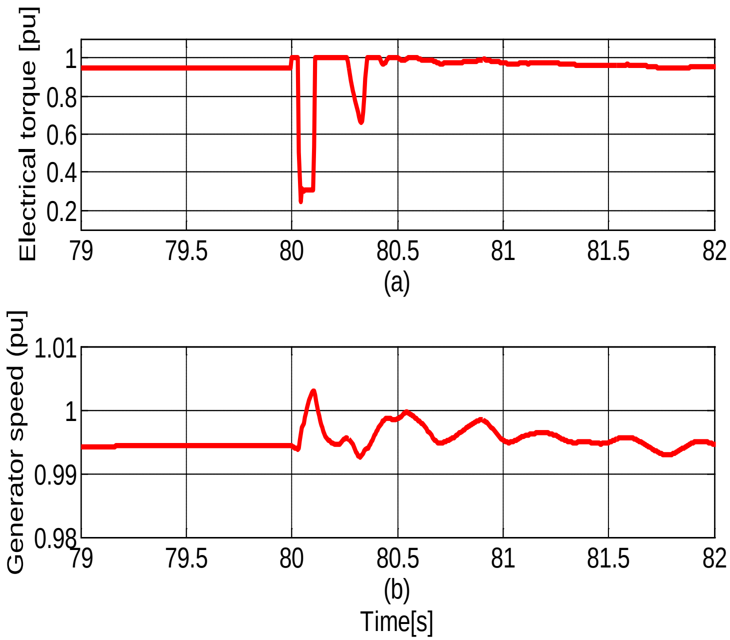
- wind speed of 11 m/s => 90% of rated power
- symmetrical 3 phase fault for 100ms
  - 80% voltage dip at the stiff grid (u_{grid})
  - 50% voltage dip at turbine connection point
- artefact of the simplified modeling of electrical system
  - converter terminal voltage and reactive power do not immediately return to the pre-fault value after fault clearance
  - additional simulation effect around 80.3 seconds in all the curves
  - does not affect the conclusions of this study regarding mechanical system response to a grid fault
- Study cases
  - Case 1: still water
  - Case two: Wave conditions





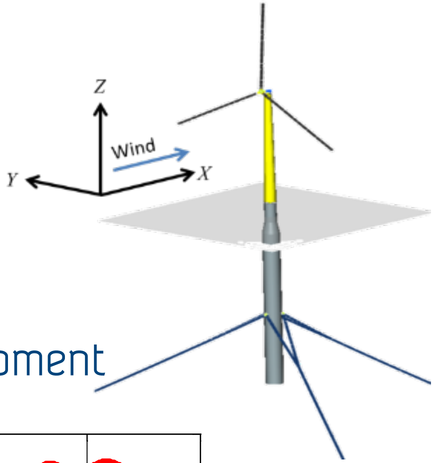
Electrical results



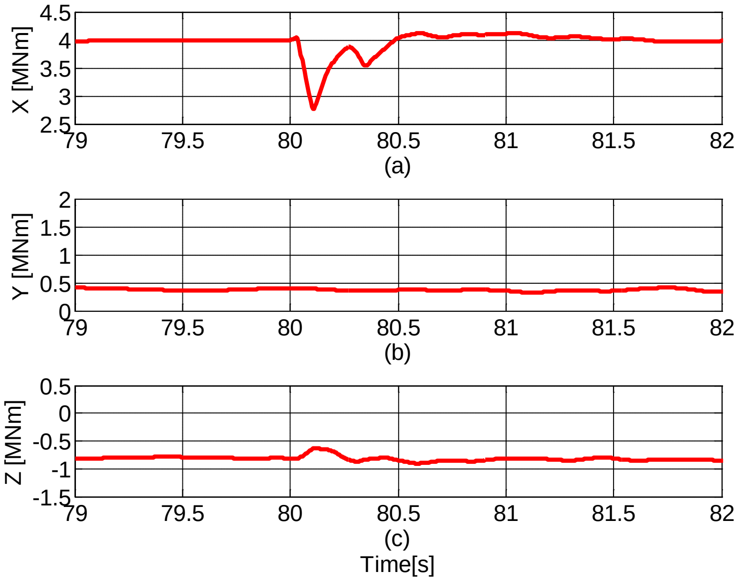


- DC-link voltage control using de-loading loop is achieved by reducing the reference electrical torque linearly when the DC-link voltage exceeds the pre-defined value (1.2pu)
- Reduction in electrical torque causes an increase in rotor speed which leads to conversion of aerodynamic input power into kinetic energy

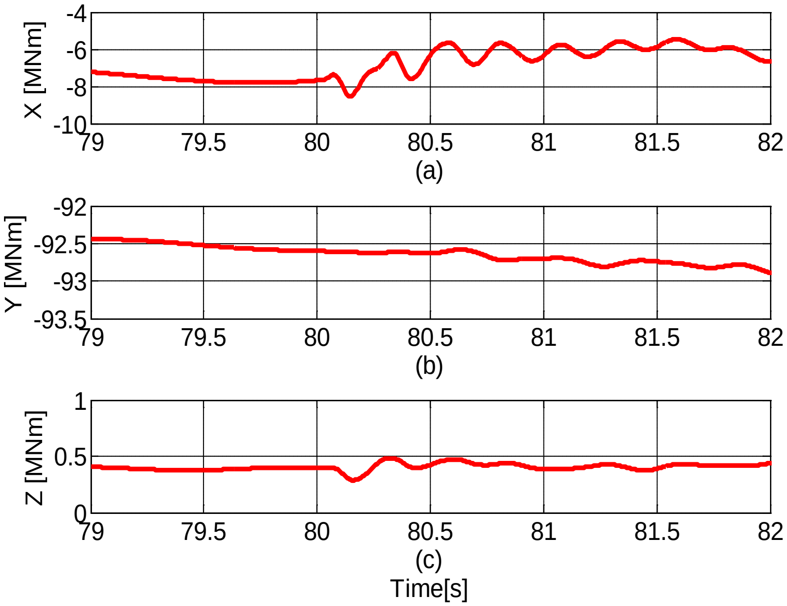
Tower bending moments: still water



Tower top bending moment



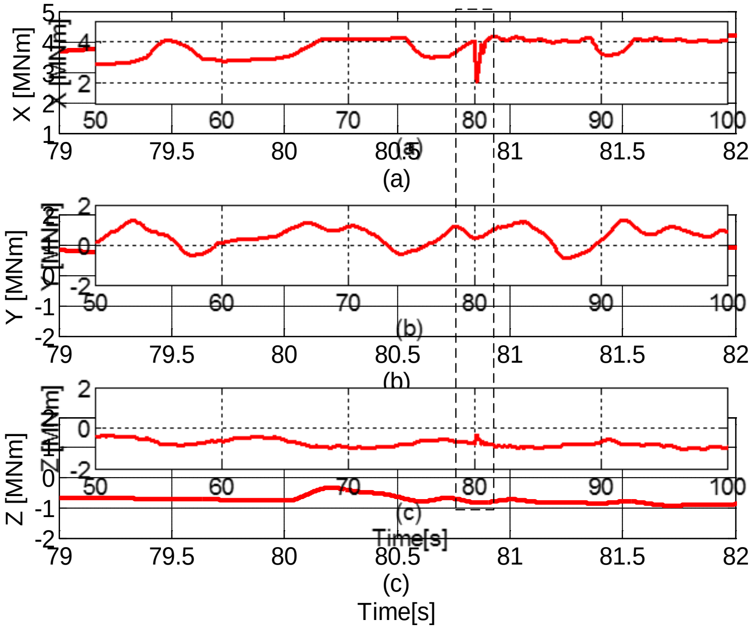
Tower bottom bending moment



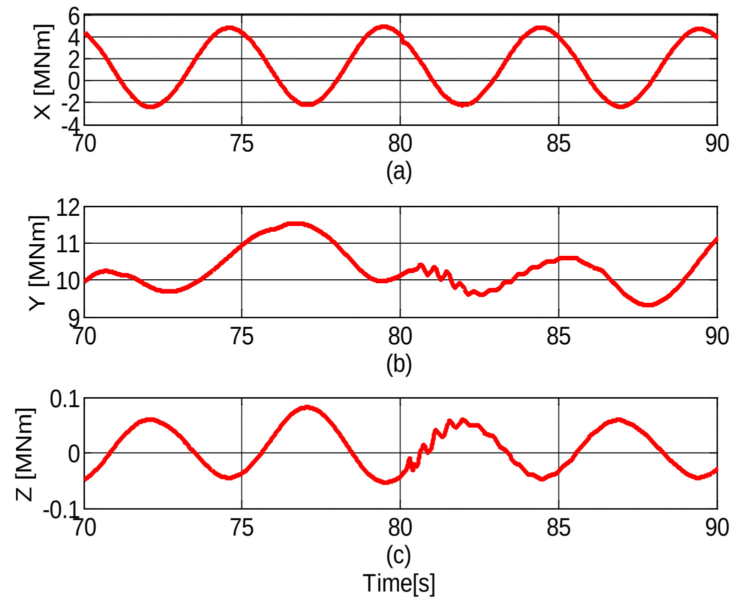
- (a) around X-axis (wind direction), (b) around Y-axis, and (c) around Z-axis
- tower bending moment around the X- and Z-axis are affected by the fault

Tower bending moments: Wave conditions

Tower top bending moment



Tower bottom bending moment



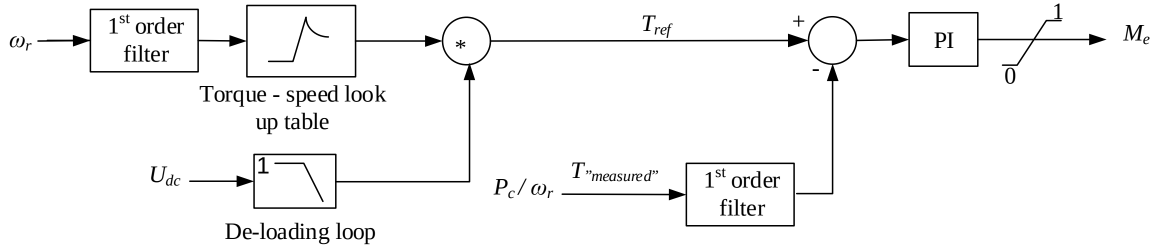
(a) around X-axis (wind direction), (b) around Y-axis, and (c) around Z-axis

- significant wave height of 6m and spectra peak period of 11 seconds
- The results for the electrical outputs are similar to that of the no wave condition

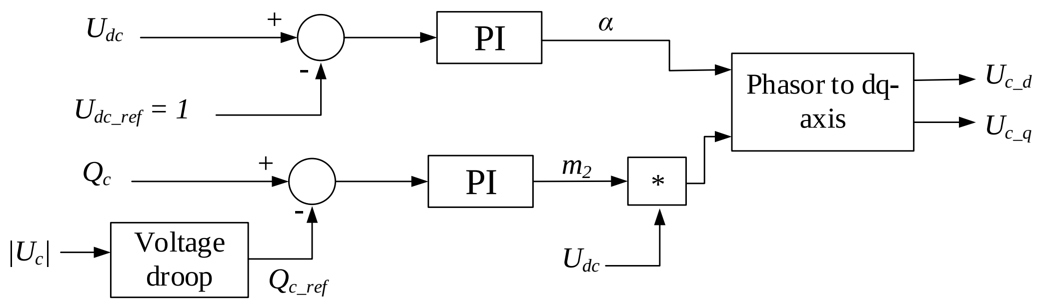
Conclusion

- integrated model platform suitable for detailed analysis of grid and floating wind turbine interactions has been presented and demonstrated
- floating turbine's response to a symmetrical three phase grid fault, that caused a 50% voltage drop at the turbine converter's terminal, was studied
- the turbine rides through voltage-dip without severe effects on electrical systems
- In the mechanical system, significant, but not critical, dip in tower top bending moment around the X-axis, direction parallel to the wind, was observed
- tower-top bending moment fluctuations observed in these two cases are about 30% and 50%. This is comparable to aerodynamic load fluctuations of 30% due to turbulence and is believed not to be critical and not a driving factor for turbine design
- simulation results may be validated using measurements from actual fault cases, or through a controlled setup using of a short-circuit emulator such as the 8 MVA DipLab facility

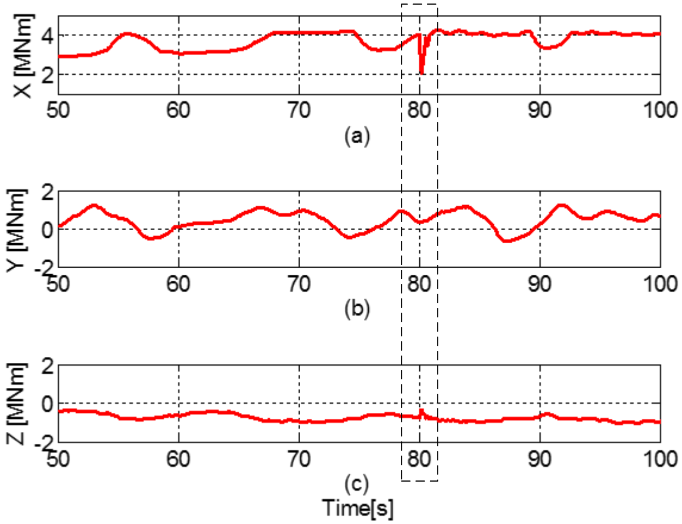
Generator speed control

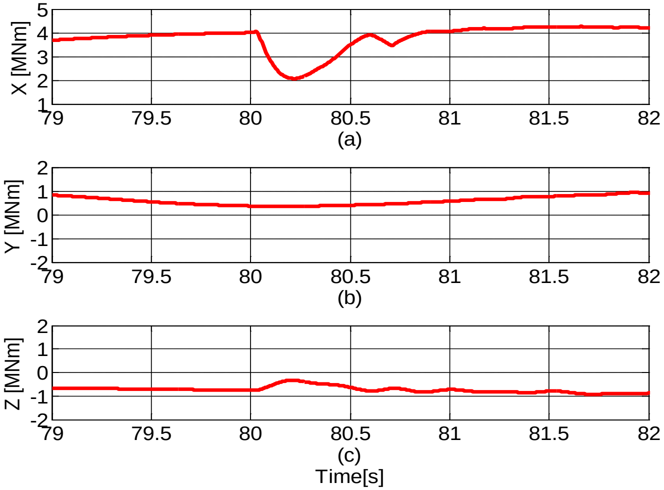


Grid side converter control



Tower top bending moments in sea wave conditions





(a) around X-axis (wind direction), (b) around Y-axis, and (c) around Z-axis