Development and testing of an advanced wind turbine control design tool

Stoyan Kanev & Jessica Holierhoek

Rotterdam
03 February 2014

Introduction

- Wind energy has to compete with other sources of energy on **costs**
- Main focus of wind energy research is therefore: how do we reduce the cost of energy (COE)

On turbine level:

- "Equilibrium" between reducing loads and keeping power output through advanced controls
- Current state of the art in load analysis is still rather primitive

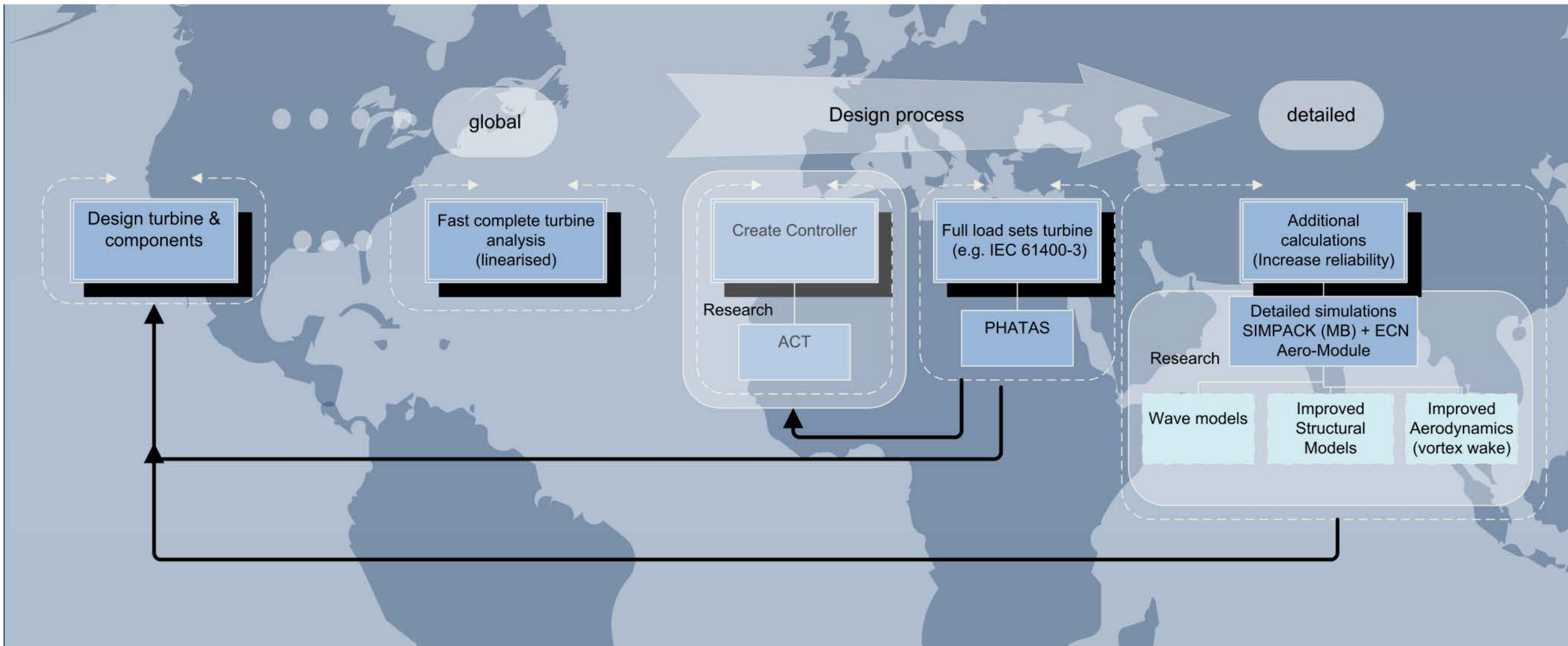
- Work done in cooperation with:

Knowledge Centre WMC

XEMC DARWIND

2-B Energy

Introduction

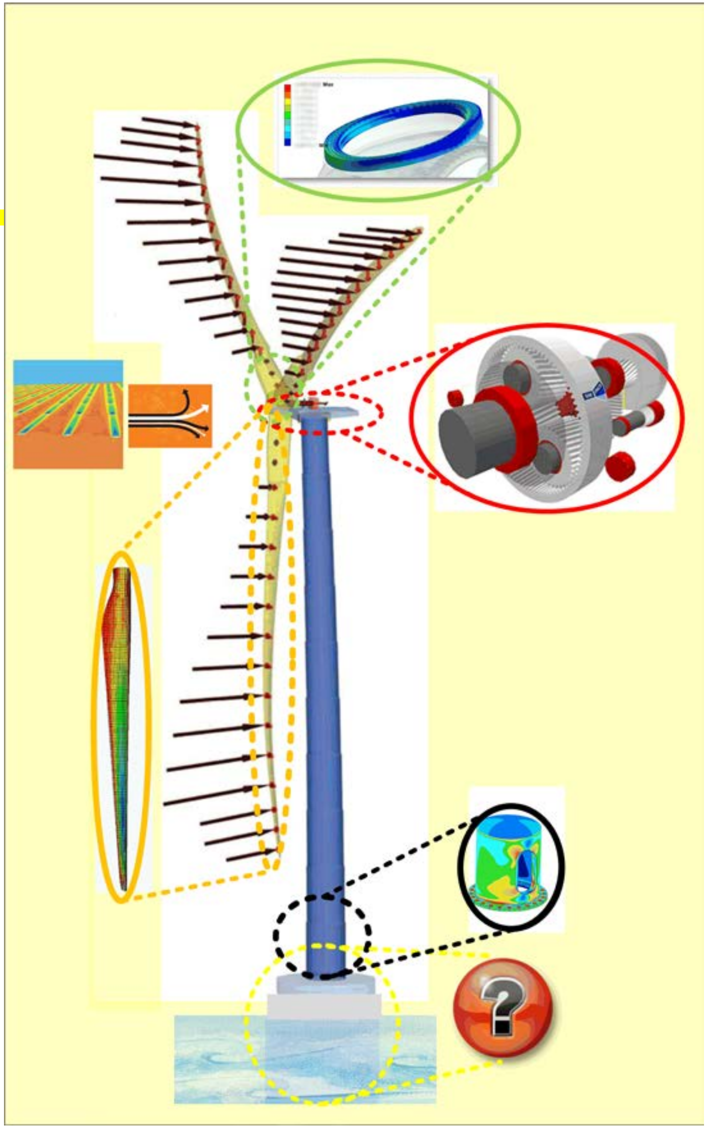


Status Load Analysis

- Current state of the art in load analysis is still rather primitive
- Load analysis is mainly based on **safety**… no blades are allowed to fly off, towers are not supposed to break, etc.
- Certification does not at all guarantee a reliable wind turbine
- For economic reasons reliability is of the upmost importance
- Due to the safety aspect, current load analysis are mostly focussed on the blades and tower
- Models of blades and tower are detailed, but other components are not

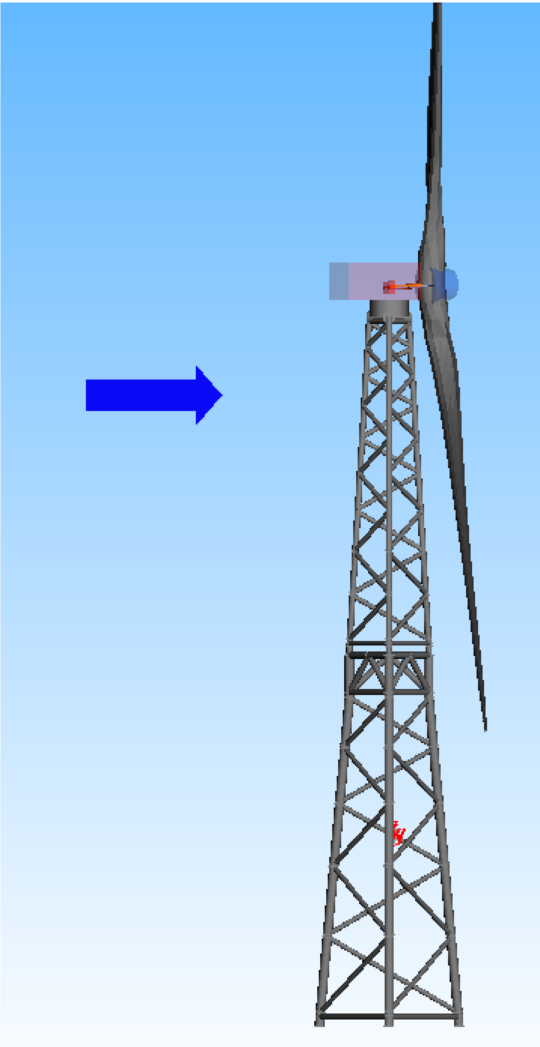
Status Load Analysis

- Some of the simplifications in the load analysis:
  - Gearbox / drive train
  - Pitch system including bearings
  - Foundation
  - Waves
  - Aerodynamics
  - Wind farm effects: operation in wake
  - Tower details
  - Blade details

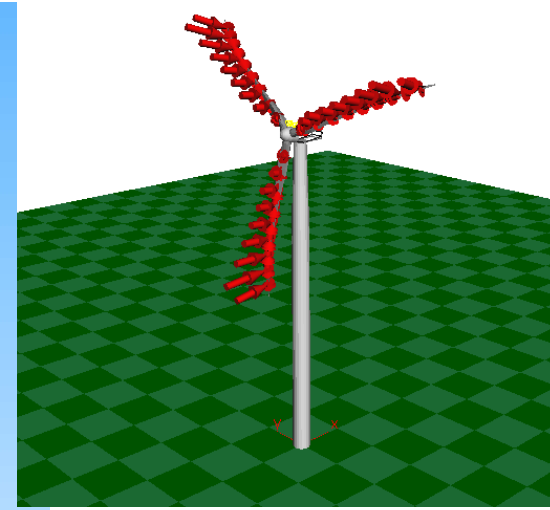


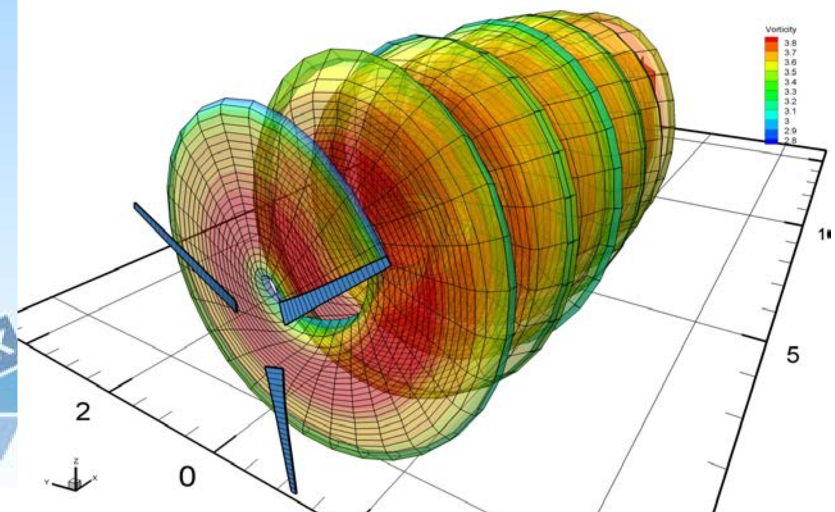
Status Load Analysis

- Sometimes components are designed based on very little information
- Interaction between the different turbine components are neglected
- Gearbox failures and pitch system failures illustrate that this methodology is not good enough for reliable design
- Therefore in these projects more detailed simulations will be run
- We could perform full FEM analysis coupled to full CFD?? But nobody has the time to run such simulations, so we need to find out:
  - Which details are relevant in the models?
  - This concerns structural modelling but also aerodynamics
  - Gives ideas of how to improve current simulation tools and design process of components
  - It can also give information for additional measurements on prototype to check the design of different components




SIM
PACK




Vorticity
2
0
5

Analysis

- Two very different turbines analysed in SIMPACK and coupled to the ECN Aero-Module (2 bladed vs 3 bladed, jacket tower, down wind vs up wind, gearbox vs direct drive…)
- Blades are modelled with more detail than WT software
- Tower model is more detailed
- Code was validated using ECN 2.5 MW test turbine measurements
- Components looked at: yaw system, pitch system, drive train, jacket tower, **controller**,…
- Aerodynamic options: ECN Aero-Module enables the use of BEM and free vortex model (‘AWSM’: free wake or prescribed wake).
- Compare BEM and AWSM for IPC cases: how does BEM perform compared to AWSM, do we need additional BEM corrections?

Control design

Objectives control tool

- **Goal**: Develop an Advanced Control design Tool (ACT), available to the industry, for design of advanced industrial controllers with active loads reduction capabilities.

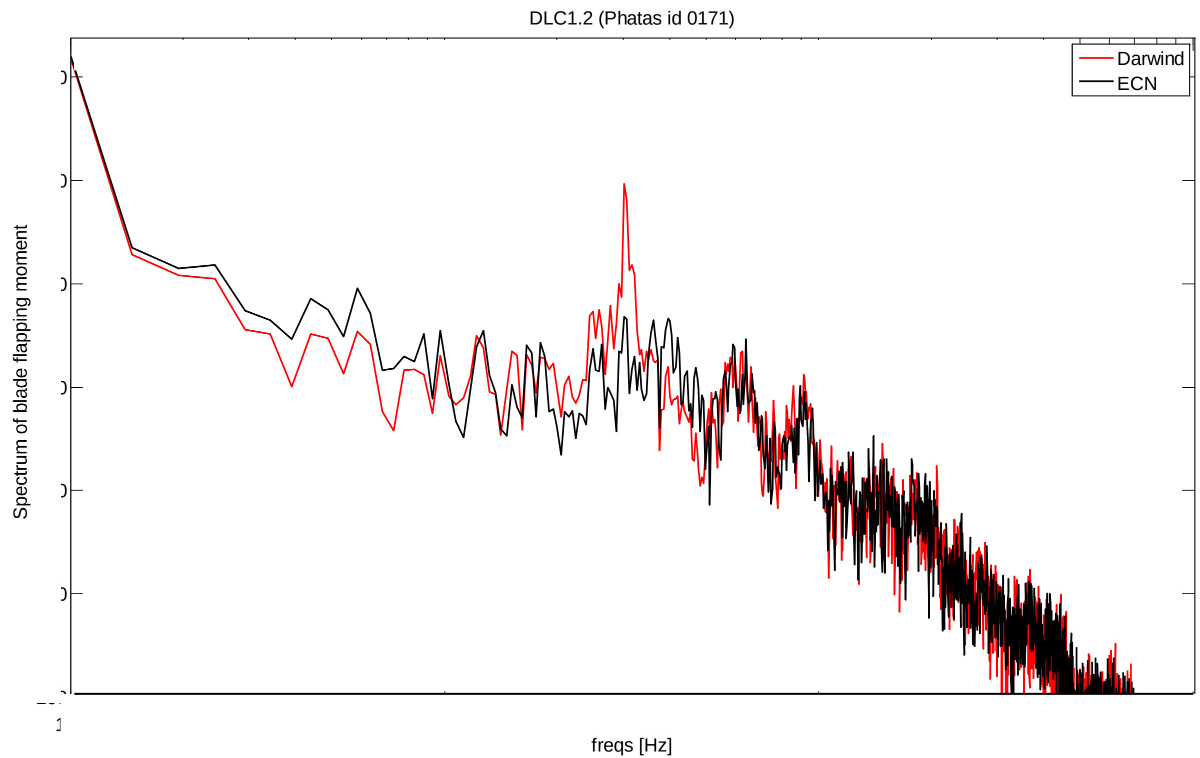
- **Objectives**
  - Create wind turbine model for control design and analysis (P201101-0014-ECN)
  - Create controller design tool (P201101-0014-ECN and P201204-003-ECN)
  - Verify controller on the 2B6 and XD115 proto's (P201204-003-ECN, P201204-003-ECN)

Highlights: features ACT

- Baseline rotor speed and power control, incl. gain scheduling
- Axial force peak shaving
- Tower fore-aft damping, incl. gain scheduling
- Tower sidewards damping
- Drive train damping
- Individual pitch control (IPC-1p, IPC-2p), incl. gain scheduling
- Extreme Event Control
- Optimal Shutdown Control
- Power setpoint adaptation (for wind farm control)
- Supervisory control features: Startup, Idling, Parked, Shutdown
- Fault Tolerant Control
- Rotor effective wind estimator

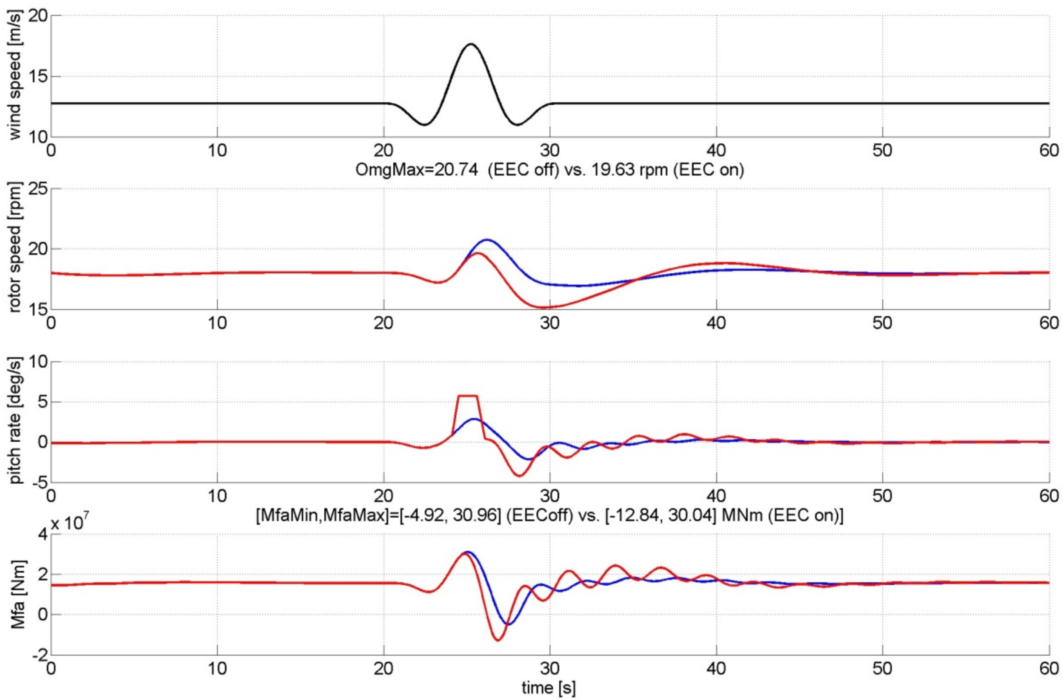
Highlights: IPC

- Typical Phatas result with IPC in full load, DLC 1.2



Highlights: Extreme event control

- Purpose: avoid overspeed and reduce extreme loads.
- Relevant for DLC 1.4 (ECD), 2.3(EOG+grid loss), 3.2 (EOG+startup)

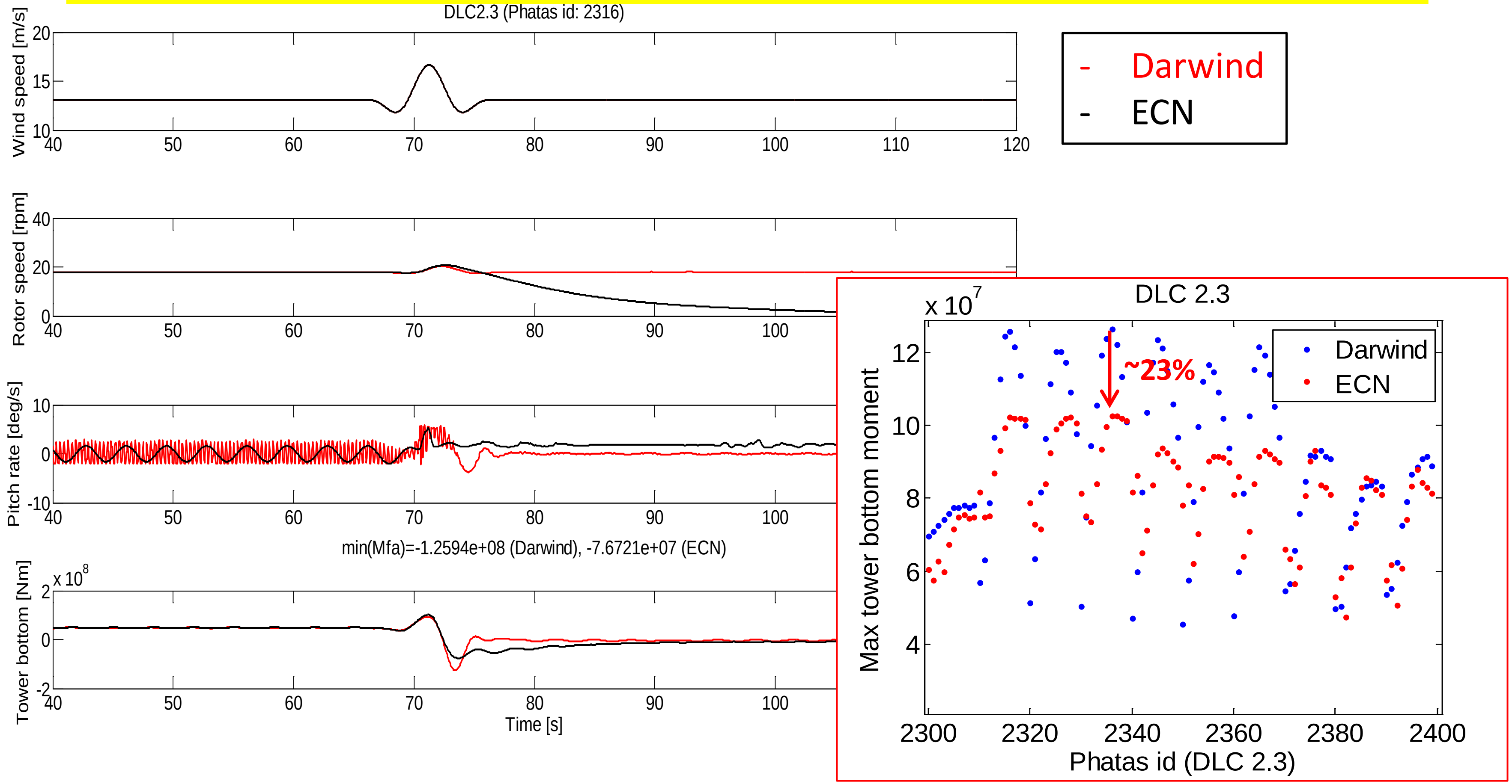


Example of EEC for EOG at 12 m/s

Optimal Shutdown Control

- Purpose: reduce extreme loads during shutdowns
- Relevant for: DLC 2.3 (EOG+grid loss)
- OSC well integrated with EEC to deal optimally with DLC2.3
- Assumed that controller controls shutdown process at least for a few seconds after grid loss
- Important here is to reduce both positive and negative tower bending moment

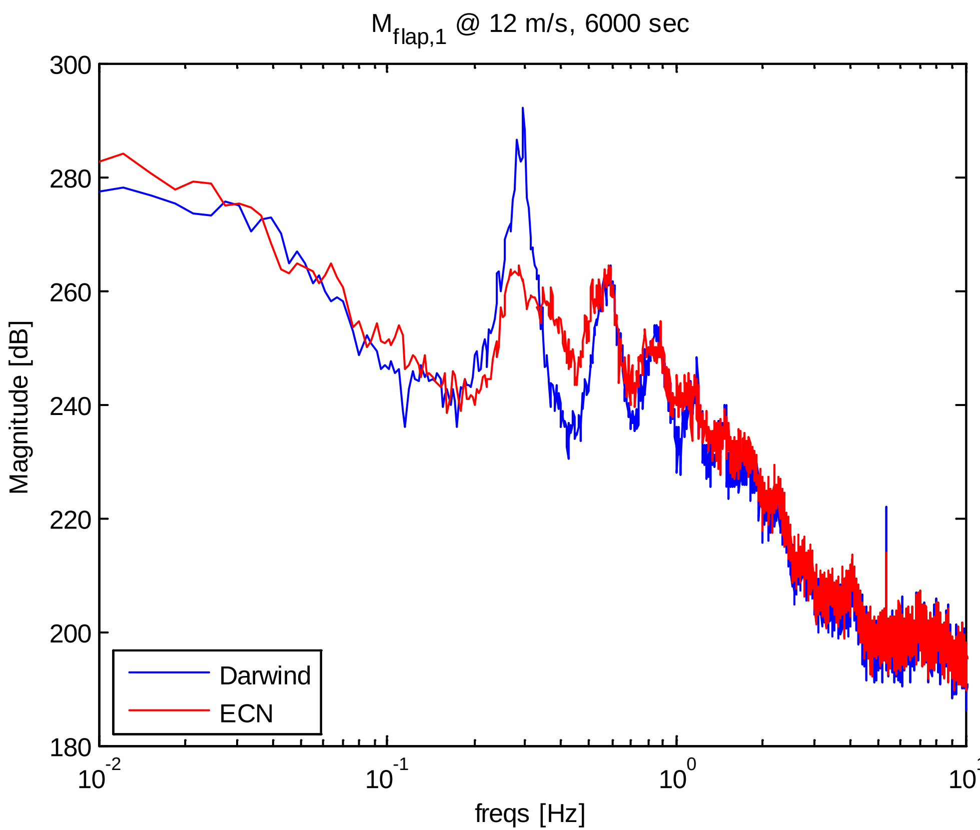
Optimal Shutdown Control



Phatas restults with XD115

Fatigue (based on DLC 1.2)	ECN vs Darwind	Comment
DEL Blade flap, lead, torsion	-11.5, -3.3, -6.5%	-22% in Bladed
DEL tower bottom fore-aft, side	+3.3, +4.2%	-2% in Bladed
DEL shaft Y, Z	-21.6, -21.2 %	-29% in Bladed
Extreme load	**ECN vs Darwind**	**Comment**
Blade flap, lead, torsion	+10, -10, +5%	+5% in Bladed
tower bottom fore-aft, side	-9, -9 %	(-23% without DLC3.2)

Field tests with IPC



Data from
27 Dec 2013

Contribution to FLOW targets

- Loads reduction & more accurate loads -> 4-5% mass reduction blades/nac/tower/foundation
- Less vibrations & more accurate loads -> less failures -> 10% less OPEX
- Less failures & better gust control -> less shutdowns -> 1.5% yield increase

Flow cost model results in

		Site type
Baseline	*162.1*	*5 MW Site A, mono-pile foundation*
Modification	*154.1*	
Cost reduction	*4.9%*	

Questions?