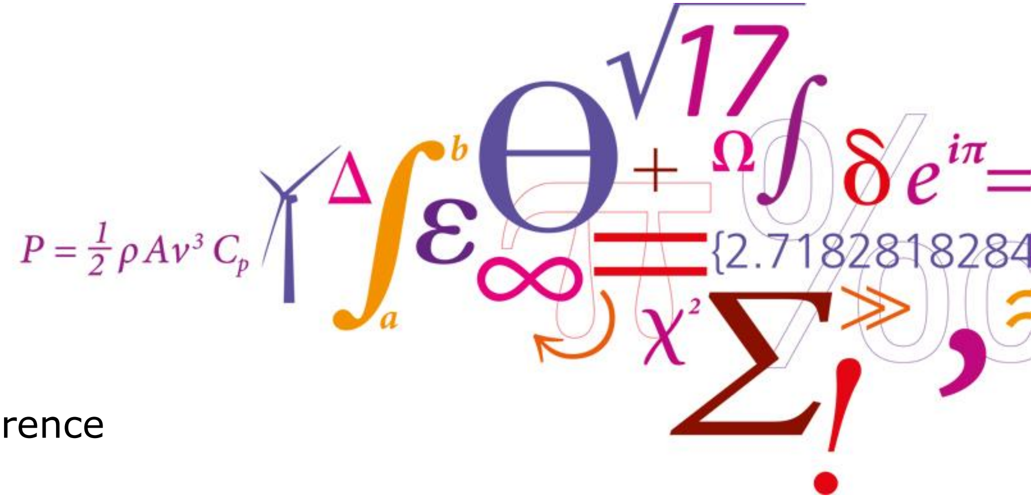
Vertical-axis wind turbine design load cases investigation and load comparison with horizontal axis wind turbine

C. Galinos, T.J. Larsen, H.A. Madsen, U.S. Paulsen
cgal@dtu.dk



13th Deep Sea Offshore Wind R&D Conference
EERA DeepWind'2016

DTU Wind Energy
Department of Wind Energy

Outline

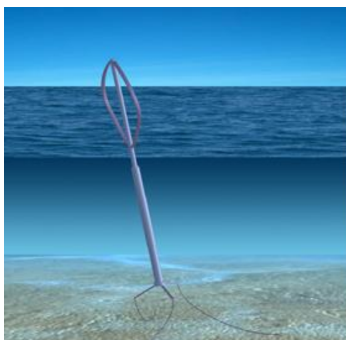
- Introduction
- Wind turbine minimum design requirements
  - Design load cases
  - Definition considerations
- Wind Turbine models
- Simulation tool
- Results
- Conclusions

Introduction

Large scale VAWT development

Past: Sandia 34m test bed, Eole 4MW, FloWind 19m

Present-Future: 5MW DeepWind concept, Nenuphar Vertiwind

Need to set the minimum design requirements for the structural integrity of VAWTs according to IEC/standardisation.

Wind turbine minimum design requirements

- IEC 61400-1 ed.3 standard sets minimum structural requirements for onshore wind turbines
  - The Design Load Cases (DLCs) are a combination of external conditions and wind turbine states
- DNV·GL similar criteria

Main research question

Are the IEC 61400-1, ed.3 DLCs applicable for vertical-axis wind turbines?

Wind turbine minimum design requirements

Design load cases

- Design situations
  - Normal power production
  - Emergency shut down
  - Parked rotor

- Not considered
  - Power production plus occurrence of fault
  - Start up and normal shut down
  - Transportation, assembly, maintenance and repair

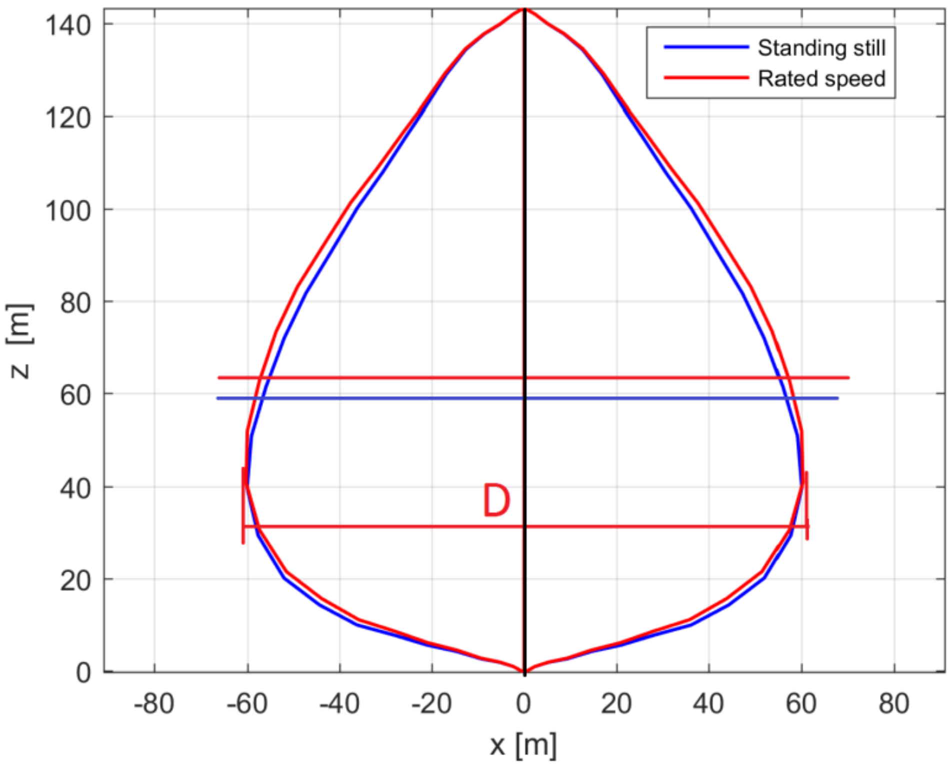
Design situation	DLC	Wind condition		Other conditions
1) Power production	1.1	NTM	$V_{in} < V_{hub} < V_{out}$	For extrapolation of extreme events
	1.2	NTM	$V_{in} < V_{hub} < V_{out}$	
	1.3	ETM	$V_{in} < V_{hub} < V_{out}$	
	1.4	ECD	$V_{hub} = V_r - 2$ m/s, V_r, $V_r + 2$ m/s	
	1.5	EWS	$V_{in} < V_{hub} < V_{out}$	
2) Power production plus occurrence of fault	2.1	NTM	$V_{in} < V_{hub} < V_{out}$	Control system fault or loss of electrical network
	2.2	NTM	$V_{in} < V_{hub} < V_{out}$	Protection system or preceding internal electrical fault
	2.3	EOG	$V_{hub} = V_r \pm 2$ m/s and V_{out}	External or internal electrical fault including loss of electrical network
	2.4	NTM	$V_{in} < V_{hub} < V_{out}$	Control, protection, or electrical system faults including loss of electrical network
3) Start up	3.1	NWP	$V_{in} < V_{hub} < V_{out}$	
	3.2	EOG	$V_{hub} = V_{in}$, $V_r \pm 2$ m/s and V_{out}	
	3.3	EDC	$V_{hub} = V_{in}$, $V_r \pm 2$ m/s and V_{out}	
4) Normal shut down	4.1	NWP	$V_{in} < V_{hub} < V_{out}$	
	4.2	EOG	$V_{hub} = V_r \pm 2$ m/s and V_{out}	
5) Emergency shut down	5.1	NTM	$V_{hub} = V_r \pm 2$ m/s and V_{out}	
6) Parked (standing still or idling)	6.1	EWM	50-year recurrence period	
	6.2	EWM	50-year recurrence period	Loss of electrical network connection
	6.3	EWM	1-year recurrence period	Extreme yaw misalignment
	6.4	NTM	$V_{hub} < 0,7\ V_{ref}$	
7) Parked and fault conditions	7.1	EWM	1-year recurrence period	
8) Transport, assembly, maintenance and repair	8.1	NTM	V_{maint} to be stated by the manufacturer	
	8.2	EWM	1-year recurrence period	

IEC 61400-1,ed.3 DLCs p35

Wind turbine minimum design requirements

Considerations of the IEC 61400-1 ed.3 for VAWTs

1. The **hub-height** where the wind reference values are applied
   - In this study the rotor swept area (projected area) centre location at nominal rotor speed

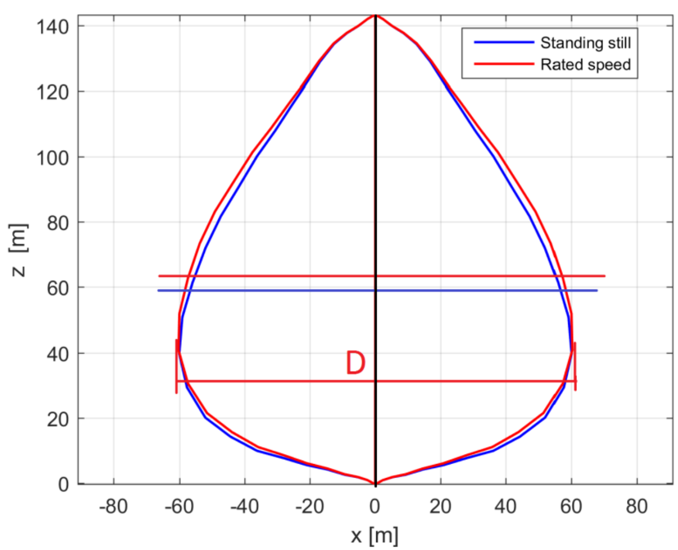


Darrieus-VAWT

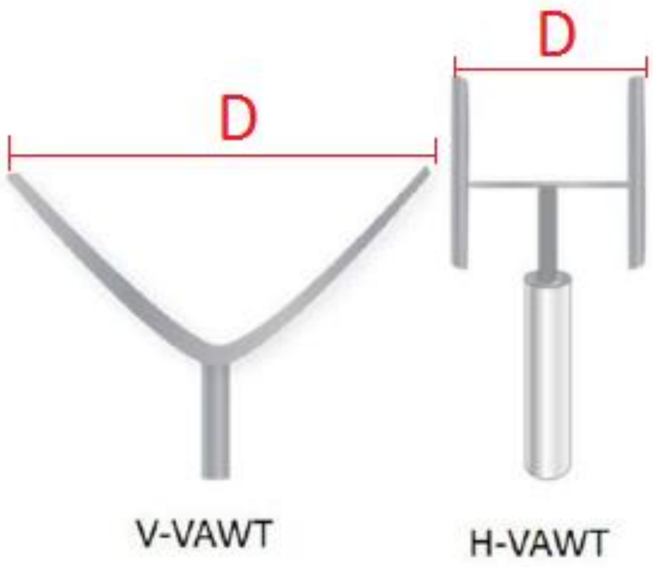
Wind turbine minimum design requirements

Considerations of the IEC 61400-1 ed.3 for VAWTs

1. The **hub-height** where the wind reference values are applied
   - The rotor swept area (projected area) centre location at nominal rotor speed



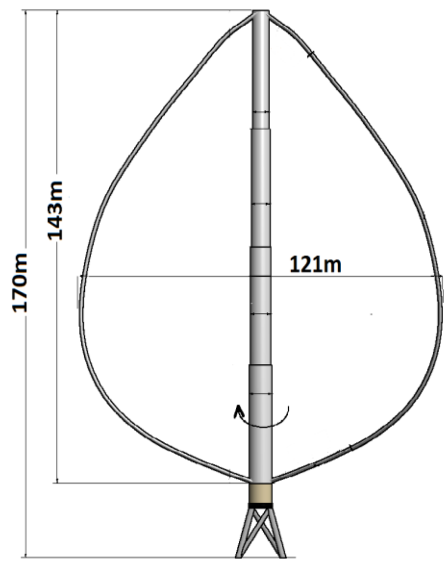
Darrieus-VAWT

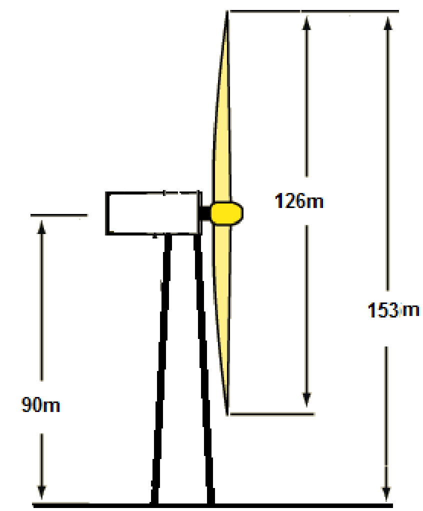


2. The **rotor diameter** is used in equations for the definition of the wind characteristics
   - The largest rotor diameter of the wind turbine at nominal rotor speed

Wind turbine models and aeroelastic code

	VAWT	HAWT
Model	Modified DeepWind rotor	NREL reference wind turbine
Rated electrical power	5 MW	5 MW
Number of blades	2	3
Power regulation	Stall	Pitch



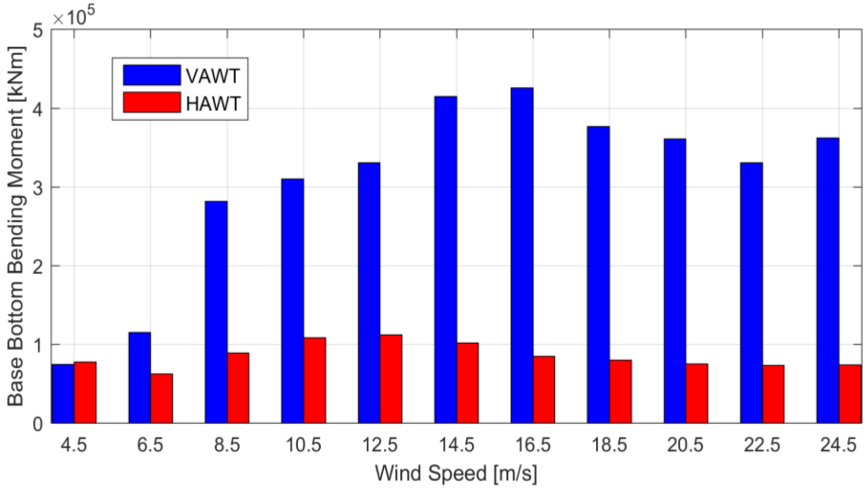


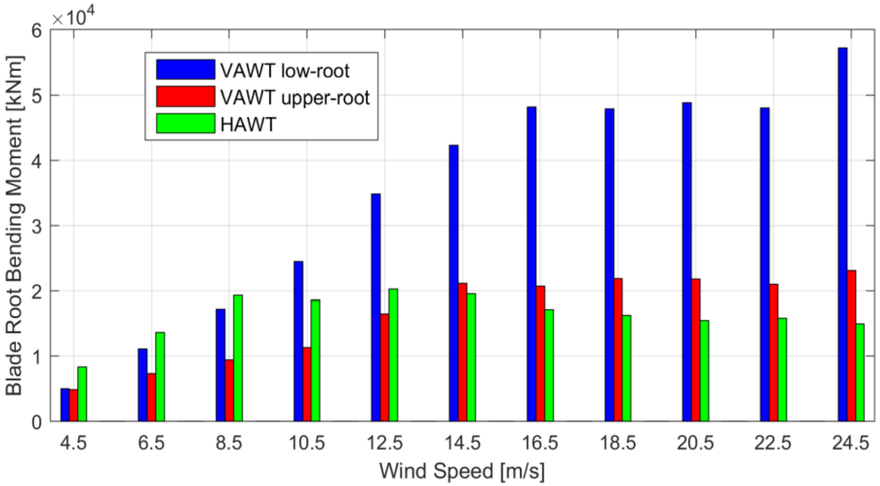
- **Simulation Tool:** HAWC2 aeroelastic code
- **Outputs:** Turbine base bottom BM, blade root BM, blade deflection

Simulation results

Power production under NTM

- Extrapolated 50 year return period extremes VAWT-HAWT



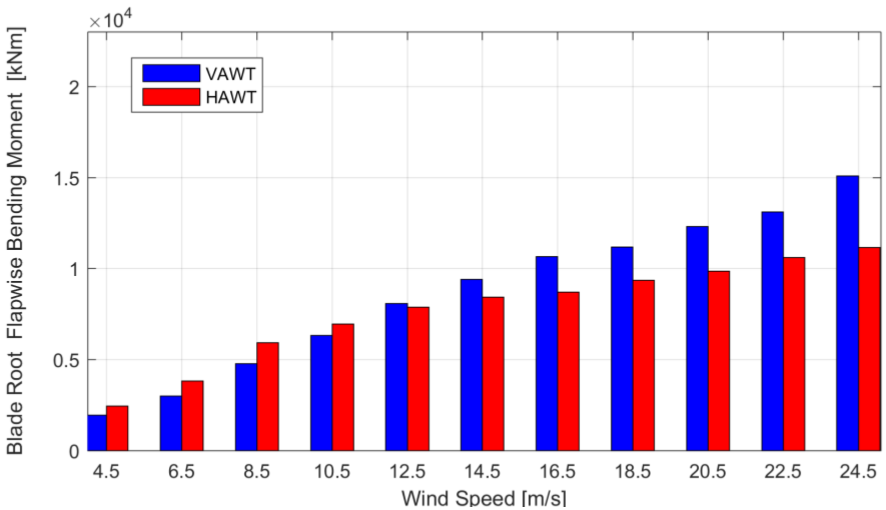


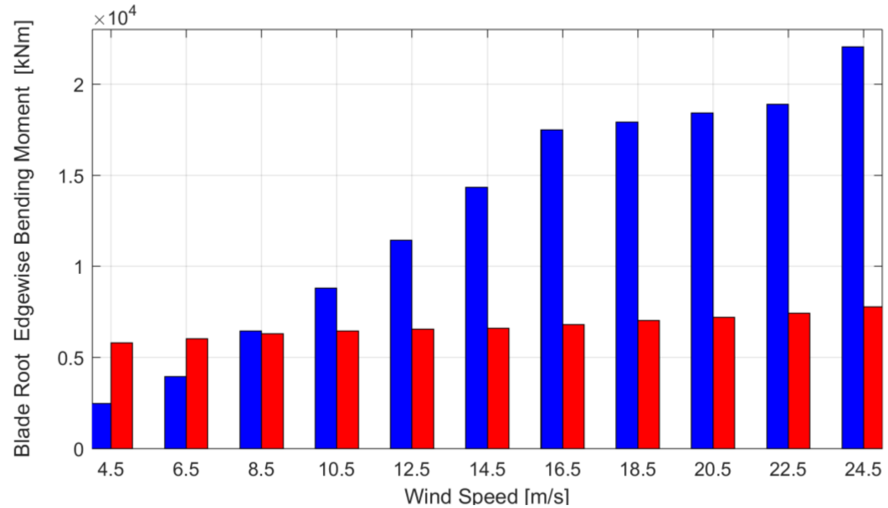
1. Larger turbine base BM for VAWT
2. VAWT blade upper root BM similar with HAWT blade root

Simulation results

Power production under NTM

- Blade equivalent 1Hz fatigue VAWT-HAWT

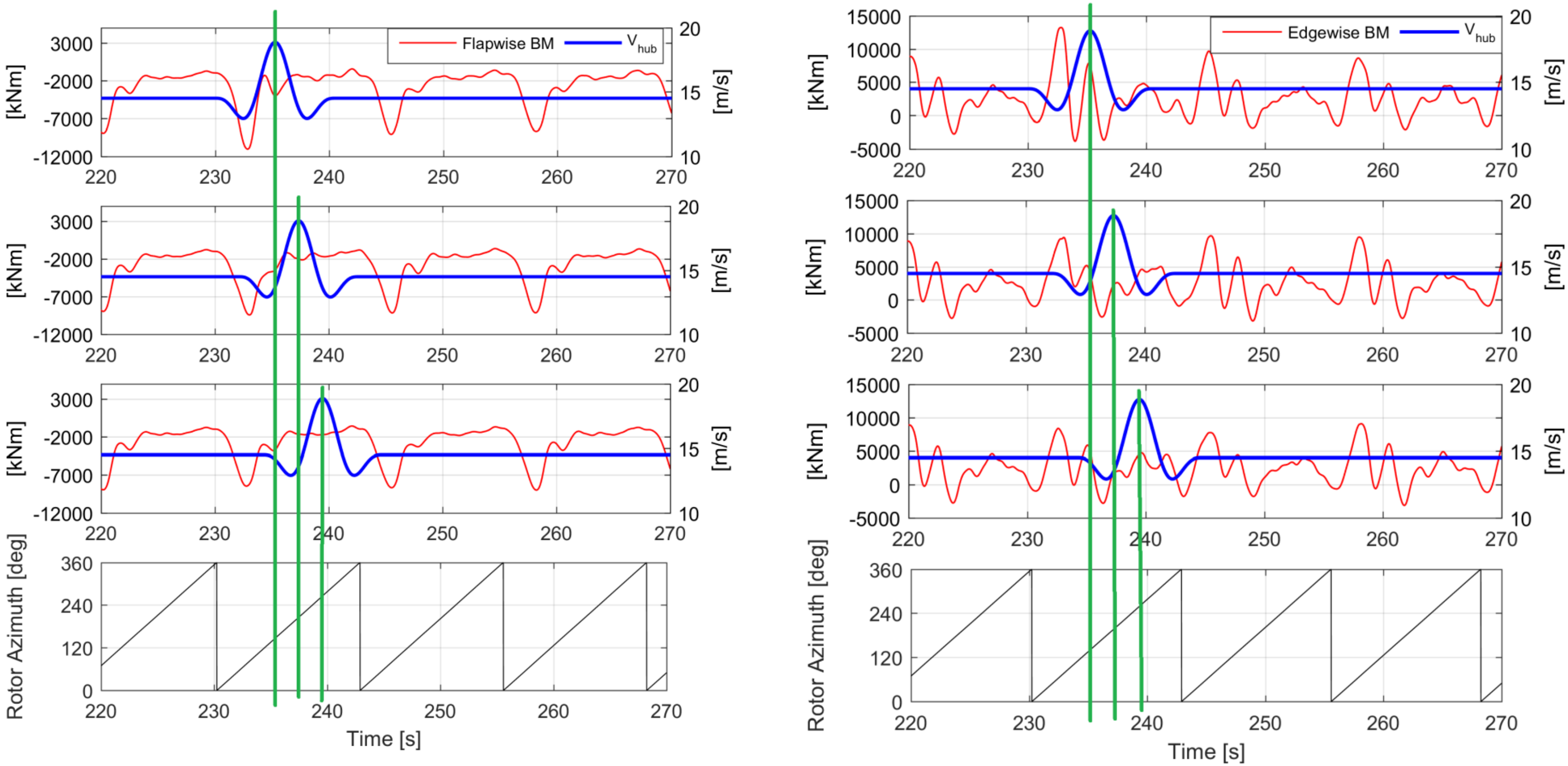




1. Flapwise BM similar magnitude
2. VAWT edgewise BM much larger at high winds

Simulation results

Extreme Operating Gust VAWT



- Loads depend on the rotor orientation during the gust passage (rotor extends in 3-dimensions)

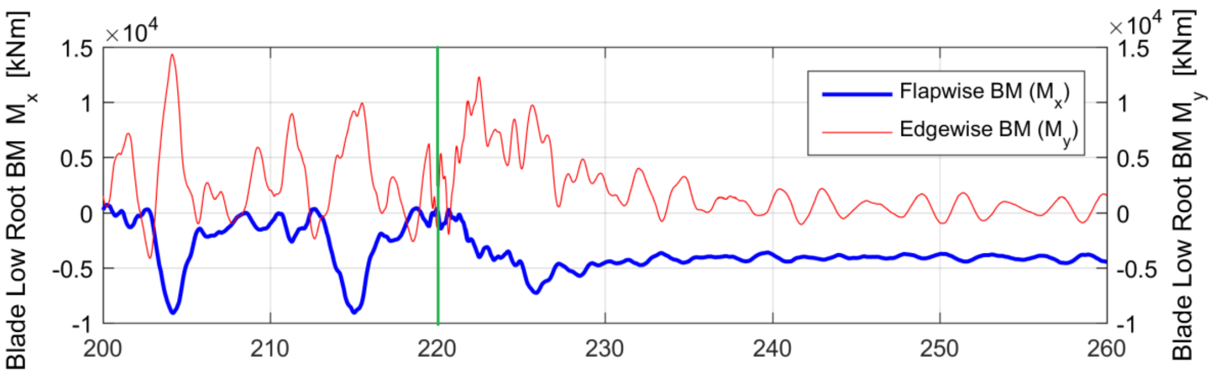
Simulation results

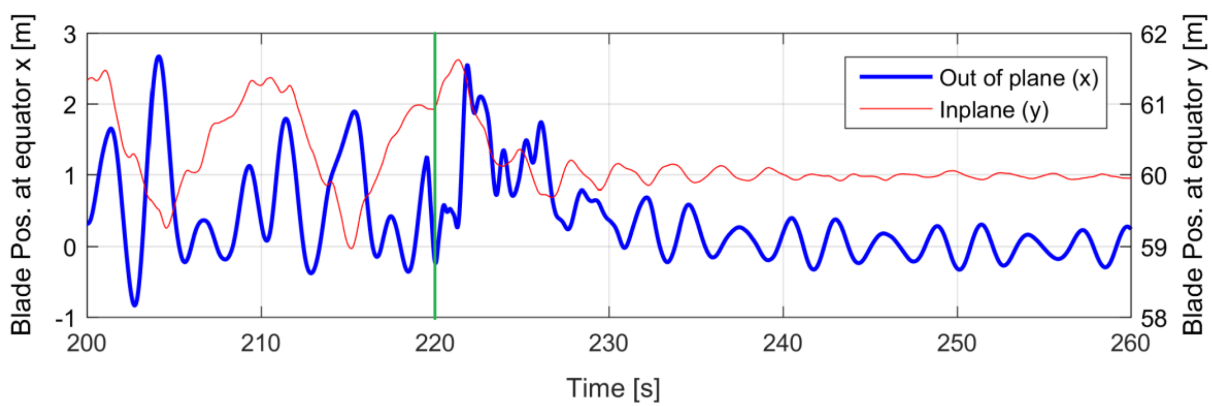
Emergency Shut Down VAWT

- Mechanical brake
- Emergency shut down at 220s
- 0.5s before grid loss (zero generator torque)

Set-up

1. Turbine deceleration to 10%ω_{rated} within 11s
2. Blade loads & deformation not extreme

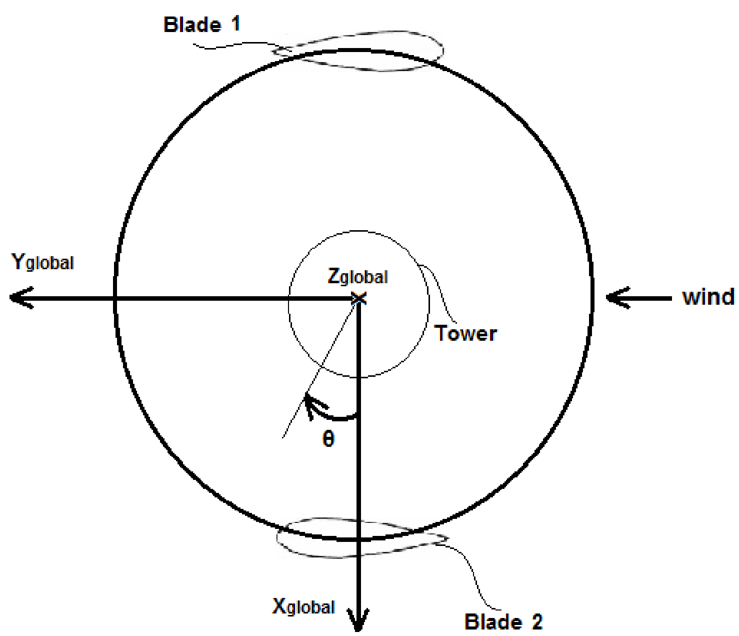




Simulation results

VAWT Parked Rotor under 50-year EWM

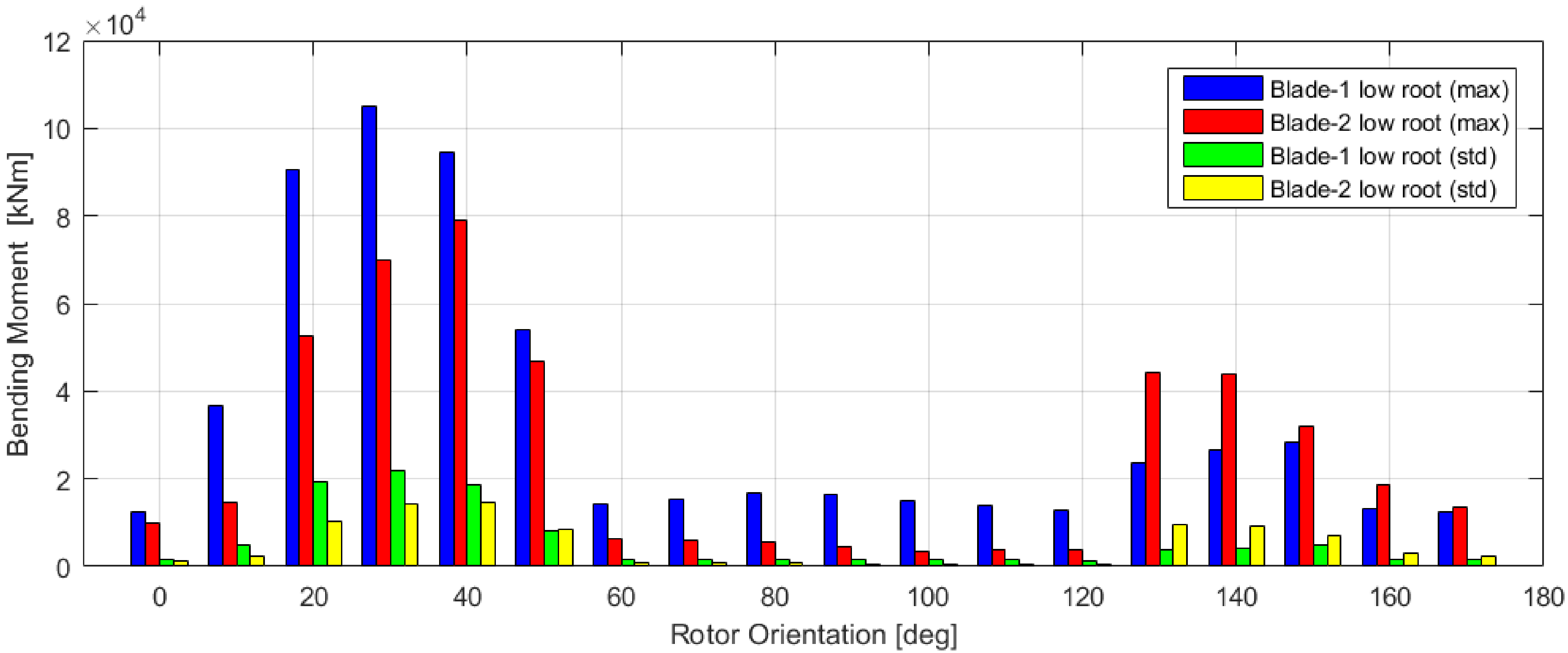
1. Idling rotor → non reaching equilibrium rotor speed
2. Forced rotor rotation at low rotor speed → Possible
3. Standing still (locked rotor at different orientations) → Blade instabilities



Simulation results

VAWT Parked Rotor under 50-year EWM

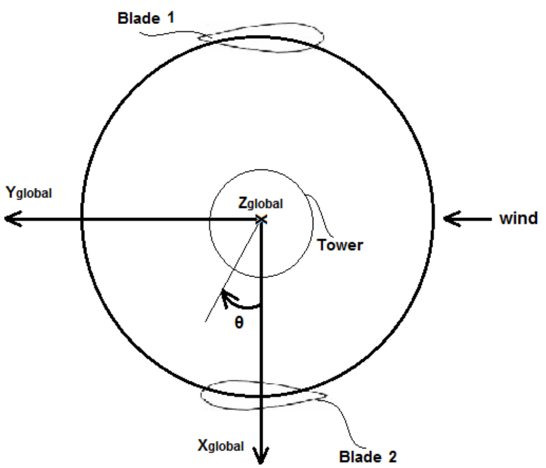
1. Idling rotor → non reaching equilibrium rotor speed
2. Forced rotor rotation at low rotor speed → Possible
3. Standing still (locked rotor at different orientations) → Blade instabilities

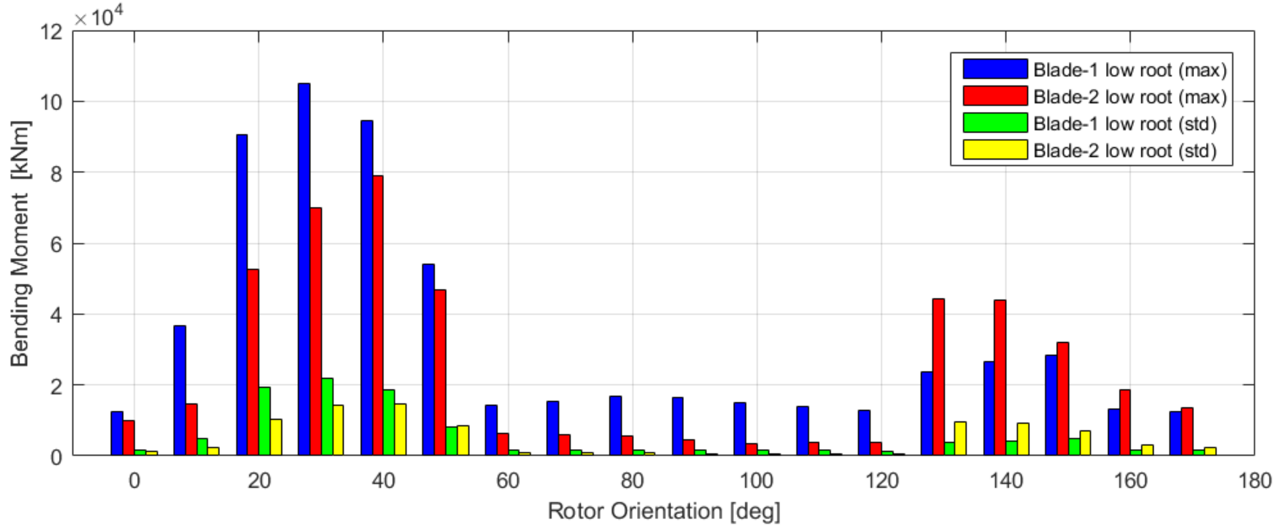


Simulation results

VAWT Parked Rotor under 50-year EWM

1. Idling rotor → non reaching equilibrium rotor speed
2. Forced rotor rotation at low rotor speed → Possible
3. Standing still (locked rotor at different orientations) → Blade instabilities

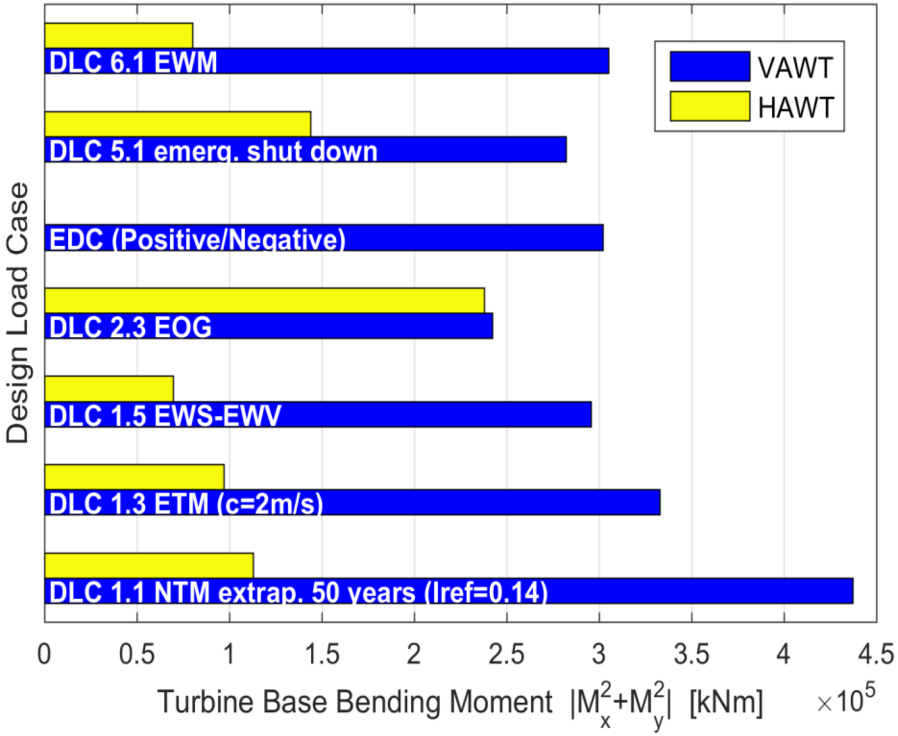


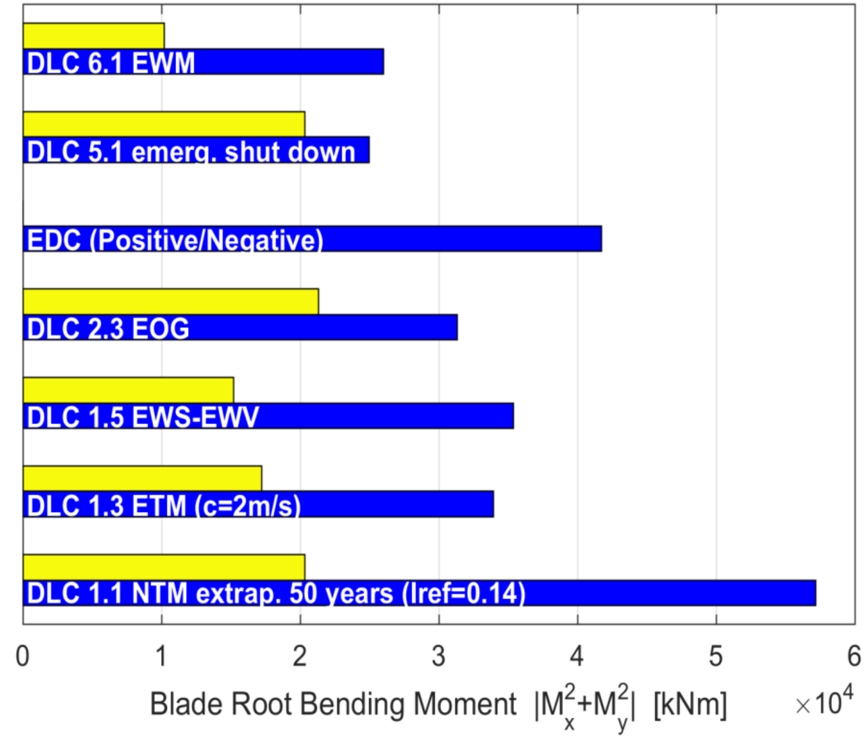


- Sensitivity analysis on blade stiffness and damping for the standing still case → Instabilities present

Simulation results

Comparison of DLCs VAWT-HAWT





1. VAWT extreme loads emerged from DLC 1.1 higher than the transient wind events
2. HAWT load results from transients more severe (DLC 2.3)

Conclusions

VAWT DLCs

1. The examined DLCs of IEC 61400-1, ed.3 are applicable for VAWTs
2. Definitions of equivalent hub height and rotor diameter were specified
3. The loads emerged from EOG depend on the rotor orientation - gust passage combination (3D rotor in space)
4. Parked standing still rotor under extreme winds (DLC 6.2) led to blade instabilities for specific rotor orientations and seems be design driver for VAWTs

Conclusions

VAWT-HAWT load comparison

1. Under power production with NTM both VAWT ultimate and 1 Hz fatigue base bottom bending moments were higher compared to the HAWT
2. The blade root loads are of similar magnitude at low and moderate winds between the two wind turbines under normal power production
3. DLC 1.1 simulations returned the highest base bottom and blade root loads for the VAWT where the DLC 2.3 and 5.1 for the HAWT

The present work is a result of the contributions within the INFLOW project, supported by the European Commission, Grant No 296043, and by the INFLOW beneficiaries: NENUPHAR(F), IFP(F), EDF(F), EIFAGE(F), FRAUNHOFER(D), VICINAY(E), VRYHOF(NL), and DTU(DK)