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# The X-Rotor Offshore Wind Turbine Concept

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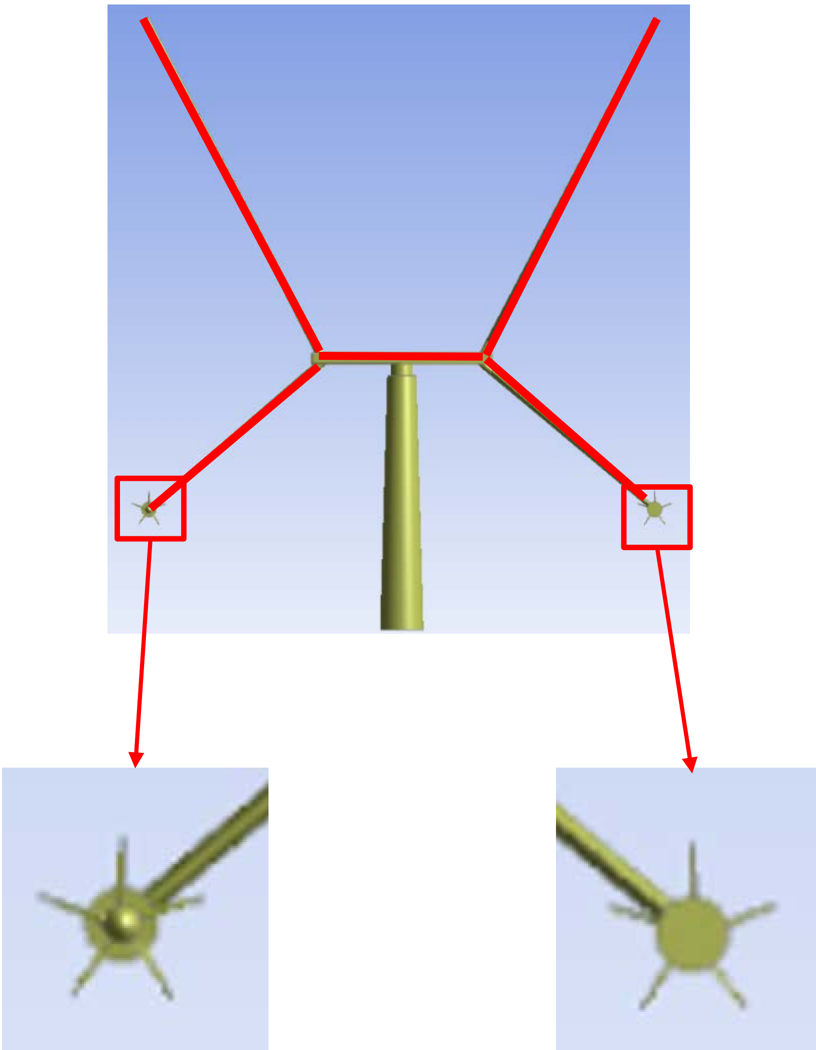
# Outline

1. X-Rotor Concept
2. X- Rotor Potential Benefits
3. Exemplary Configuration
4. Structural Analysis
5. CoE Assessment
6. Conclusion

# X-Rotor Concept



# X-Rotor Potential Concept

- Primary Rotor rotates on the vertical axis
- No Power take off on vertical axis
- High speed horizontal axis secondary rotors

- No Requirement for gearbox or multi-pole generator
- X-Shape reduces overturning moments
- Reduced requirement for Jack up vessel and reduced failure rates

# X-Rotor Benefits

1. Cost of energy reduction

2. Floating platform potential

3. Up-scaling potential

# Exemplary Configuration

1. Tip speed of the secondary rotors, $\lambda_s \lambda_p V$ , is constrained above
   - $\lambda_s$ is tip speed ratio of secondary rotors
   - $\lambda_p$ is tip speed ratio of primary rotor
   - V is wind speed
   - $(\lambda_s \lambda_p)$ is net tip speed ratio

2. Rotational speed of the secondary speed is constrained below

3. Efficiency of power conversion by the secondary rotor, $P_s/(\Omega_s T_s)$ , must be high
   - $P_s$ is power extracted by secondary rotor
   - $\Omega_s$ is rotational speed of secondary rotor
   - $T_S$ is thrust on secondary rotor

# Exemplary Configuration

To achieve high efficiency of power conversion

- Primary vertical axis rotor has high efficiency, $\lambda_p$~4 - 5.
- Secondary horizontal axis rotor has low efficiency, $\lambda_s$~3 - 4.
  maximise power for fixed root bending moment
  corresponds to induction factor of 0.2.

To keep within tip speed constraint

- $\lambda_p\lambda_s$~ 14 - 16

# Exemplary Configuration

Upper and lower primary rotors have 2 blade with single secondary rotor on each lower blade.

With generators having 4 pole pairs with nominal frequency of 25Hz suitable for turbines up to 5MW

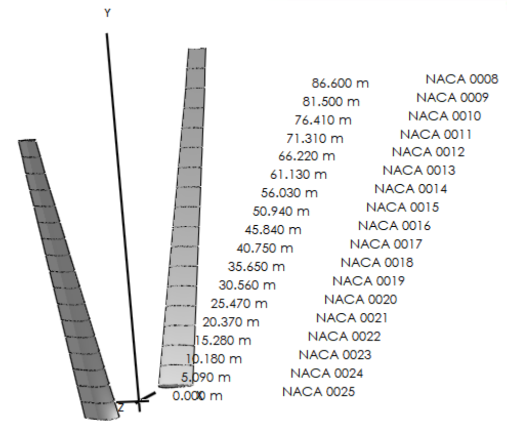
Primary rotor $C_{pmax}$= 0.39 at $\lambda_{pmax}$= 4.65 and area=12,352m$^2$

Secondary rotor $C_{pmax}$= 0.27 at $\lambda_{pmax}$= 3.13 , $C_p/C_T$=0.8 and area=139m$^2$

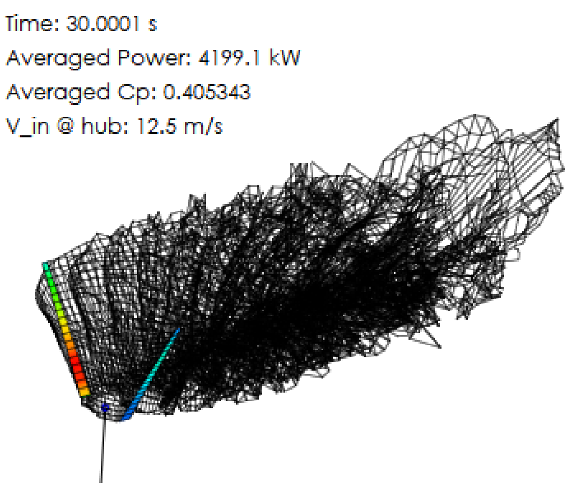
5.02MW of mechanical power is delivered in 12.66m/s wind speed, 5.50MW in 20m/s

# Structural Analysis

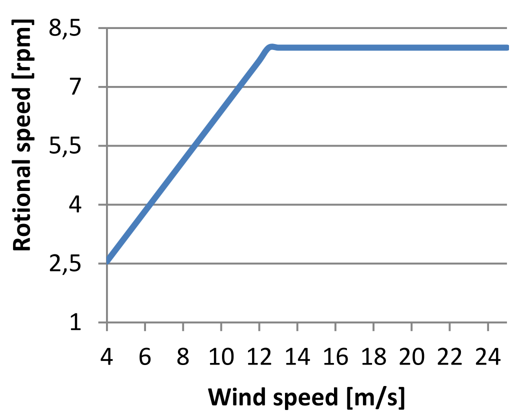
1. Chord lengths of the upper and lower blades 10 and 14 m at the blade roots, respectively
2. Chord lengths linearly reduce to 5 and 7 m at blade tips
3. NACA 0025 (root) and NACA 0008 (tip) for both upper and lower blades
4. Ideal power production of 6.47 MW at rated wind speed (12.5 m/s) and rotational speed of 0.838 rad/sec
5. Aerodynamic analysis for turbine operation simulation in QBlade



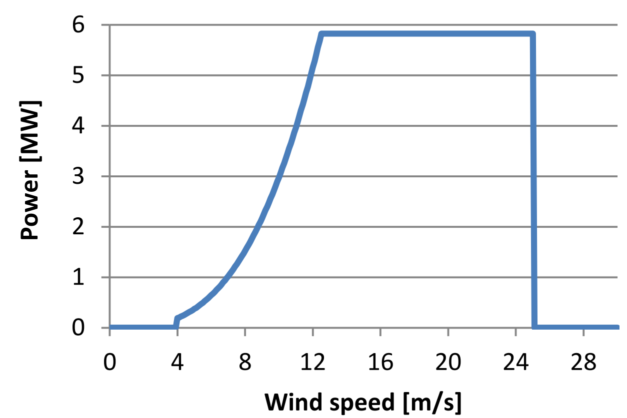

Upper rotor profile layout along blade axis




Operational load simulation, upper blades, QBlade



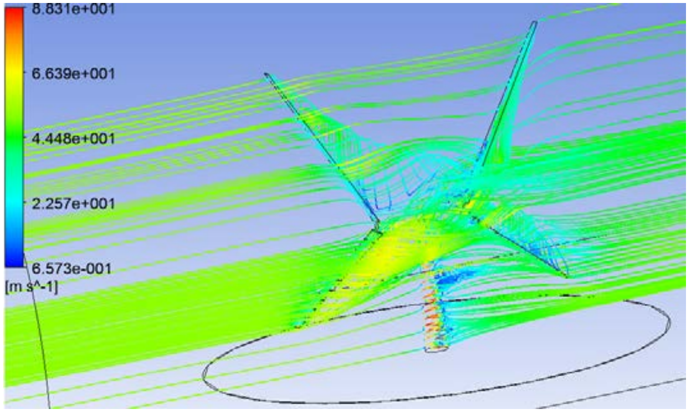

X-Rotor rotational speed curve



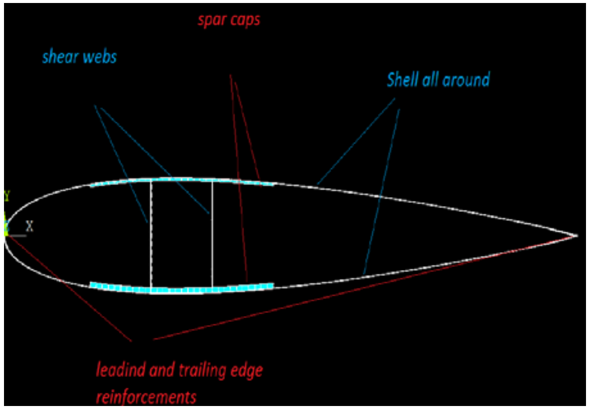

X-Rotor power curve with efficiency of 90%

# Structural Analysis

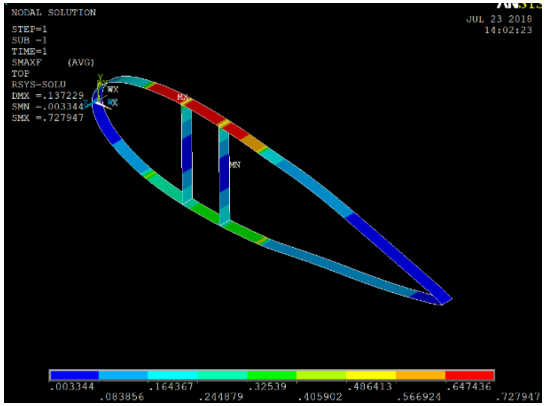
1. Blade profile pre-dimensioning based on ultimate strength criteria and strain constraints for high quality laminate
   - Rotor at parked position under extreme wind parallel to rotor plane with speed of 52.5 m/sec
   - Buckling control passed as blade stability under above conditions fulfilled
2. All designs based on IEC 61400-1:2005 and Certification of Wind Turbines, Germanischer Lloyd, 2010
3. Operational wind speeds between 4.5 - 25 m/sec




Extreme loads simulation, ANSYS CFX




Blade internals layout



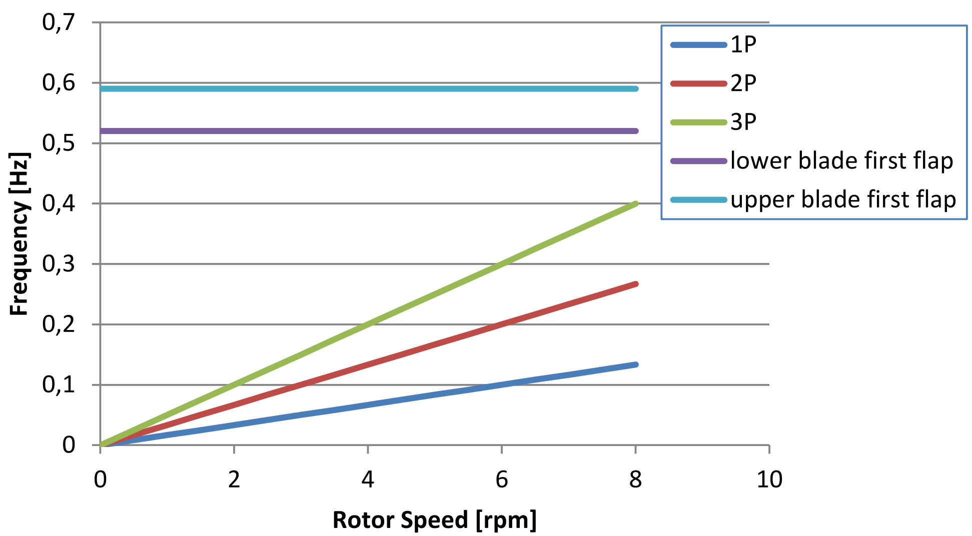

Blade profile stress analysis, NACA 0025, ANSYS mechanical

# Structural Analysis

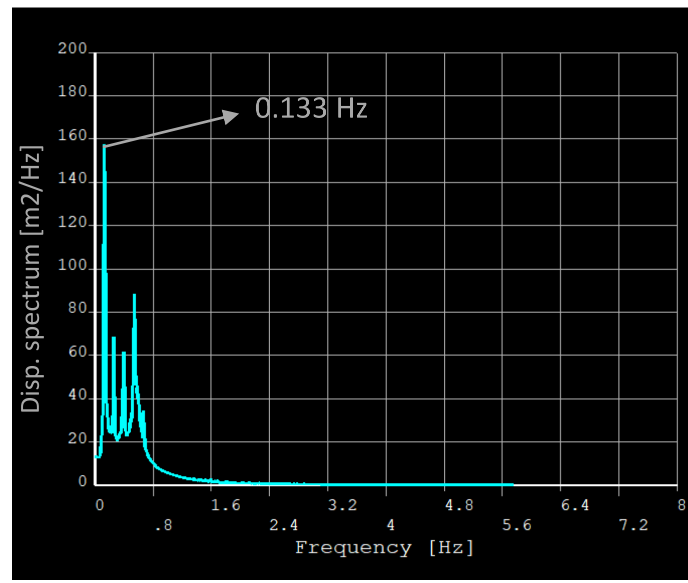
1. Mass of upper and lower blades 40500 and 23384 kg, respectively
   - Total mass of 2-blade rotor design 127768 kg

2. Modal analysis and dynamic response simulation of isolated blades
   - Blade resonance control through Campbell plot

3. HAWT blade tip deflection check irrelevant for X-Rotor, due to its special design
   - Excessive tip deflection prevented




Rotor blades Campbell plot




Power spectrum of upper blade at rated wind speed (12.5 m/sec), rotor speed 8 rpm (0.133 Hz)

# Cost of Energy

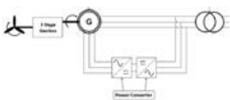
Capital costs differences between X-Rotor and existing HAWTs:

**Savings on no Gearbox and no multi-pole Generator**

Comparison to different drive-train configurations

Vs

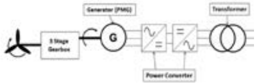
3 Stage DFIG



= 5% Less Turbine Cost

Vs

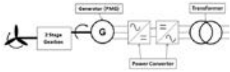
3 Stage PMG



= 10% Less Turbine Cost

Vs

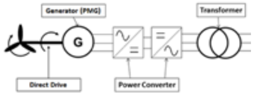
2 Stage PMG



= 20% Less Turbine Cost

Vs

DD PMG



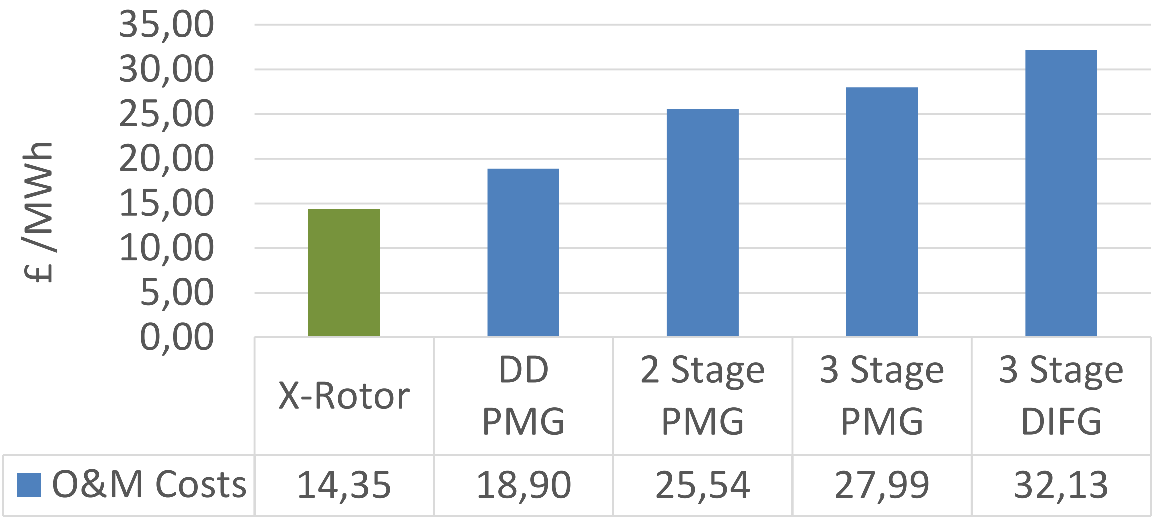
= 32% Less Turbine Cost

**X-Rotor capital cost on average 17% lower than existing HAWT turbine costs**

**Rotor mass and consequently cost similar to existing HAWTs**

# Cost of Energy

- X-Rotor O&M costs compared to 4 different turbine types
- Strathclyde O&M cost model used
- Model inputs adjusted to represent the X-Rotor
- O&M costs from existing turbines come from a published paper
- Same methodology and hypothetical site used for like for like comparison with results




- **X-Rotor O&M costs 43% lower than the average O&M cost for four existing turbine types**

- No gearbox or multipole generator failures.
- Greatly reduced requirement for Jack-up vessel.

# Cost of Energy

X-Rotor CoE comparison with existing turbines:

- X-Rotor average **capital costs savings** compared existing turbines is **17%**
- X-Rotor average **O&M cost savings** compared to existing turbines is **43%**

Assumptions

- O&M costs make up 30% of the overall CoE
- Capital costs make up 30% each of overall CoE

The X-Rotor CoE saving compared to existing wind turbines ranges from 22%-26% depending on existing turbine type used in the comparison.

**X-Rotor CoE on average 24% lower than existing HAWT turbine costs**

# Conclusion

- X-Rotor structure/rotor is similar cost to existing wind turbine rotors based on mass

- Turbine costs compared to existing wind turbines is on average 17% less

- O&M costs compared to existing turbines is on average 43% less

- CoE compared to existing turbines is on average 24% less

- Other investigations
  - ❑ Further exemplary designs suitable for 4MW to 7.5MW
  - ❑ Loading and design of jackets for both designs.

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