The X-Rotor Offshore Wind Turbine Concept

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Outline

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2. X-Rotor Potential Benefits
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4. Structural Analysis
5. CoE Assessment
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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, $\lambda_p \sim 4\ -\ 5$.
- Secondary horizontal axis rotor has low efficiency, $\lambda_s \sim 3\ -\ 4$. Maximise power for fixed root bending moment corresponds to induction factor of 0.2.

To keep within tip speed constraint

- $\lambda_p \lambda_s \sim 14\ -\ 16$
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 $C_{p_{\text{max}}}=0.39$ at $\lambda_{p_{\text{max}}}=4.65$ and area=$12,352\text{m}^2$

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

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
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

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.
