A Numerical Study of Active Pitch Control Vertical Axis Tidal Turbines

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In a context of development of renewable energies, there is a growing interest in marine energies. Tidal currents are promising due to the density of seawater and the predictability of tidal oscillations at a given location. Because of compactness and less sensitivity to flow direction Vertical Axis Tidal Turbines (VATT) for Marine Current Energy extraction is an interesting way that need to be reconsidered. However, the Power Coefficient (CP) of VATT is limited by the inherent variation of the blades' angle of attack i.e. the blades cannot always work at their optimal angle of attack. Depending on the tip speed ratio ($\lambda = \omega$ R / U_∞), the maximum angle of attack can reach high (>20°) or low (<10°) values. The blades may then undergo dynamic stall or relatively low loadings. Staelens et al. [1] used DMST (Double Multiple Streamtubes) calculations to show that limiting the blades' angle of attack just below the static stall angle increases the CP of the turbine. Hwang et al. [2] used CFD calculations (on a coarse grid) and a genetic algorithm to find an optimal pitching law. Their results show an increase of 25% of the power coefficient by reducing the angle of attack in the upstream half of the turbine. Paillard [3] showed, through CFD calculations, that decreasing the angle of attack in the upstream half of the turbine thanks to sinusoidal pitching laws, increases its CP. Based on these results, this paper aims at studying the effect of the blades' angle of attack decrease in the upstream half of the turbine on the power coefficient. The turbine used in this study (SHIVA) is a straight bladed VATT (3 blades), currently under construction at the French Naval Academy Research Institute for experimental measurements. The main idea is to use subsidiary motors mounted on top of each blade to control pitch variation during the main rotation. .

Two-dimensional CFD calculations are used in this study. The computational domain is divided in 3 parts (Fig. 1, left): one rotating ring containing the 3 blades and two stators (inner and outer). The GGI method is used for the two rotor / stator interfaces. The grid uses a maximum y^+ value of 1 on the blades to have a y^+ independent solution, according to Maître et al. [4]. A verification study has been carried out to ensure that the solution does not depend on the computational domain size (square of side 60 D). Time step ($\Delta\theta = 1°$) and grid convergences have also been studied. Deforming mesh is used inside the rotating ring to take into account blades' pitching. The grid quality remains good for all pitch angles.

The pitching laws used in this study consist in limiting the angle of attack of the blades to a given value, at the optimal tip speed ratio of the turbine ($\lambda = 3$). Three Pitching Laws are defined (Fig. 1, right), limiting the angle of attack to 6° (PL1), 8° (PL2) and 10° (PL3). Cubic spline interpolations are used out of the "limitation area" to ensure $\alpha = 0°$ at $\theta = 0°$ and $\theta = 180°$ as well as the continuity of the complete law.

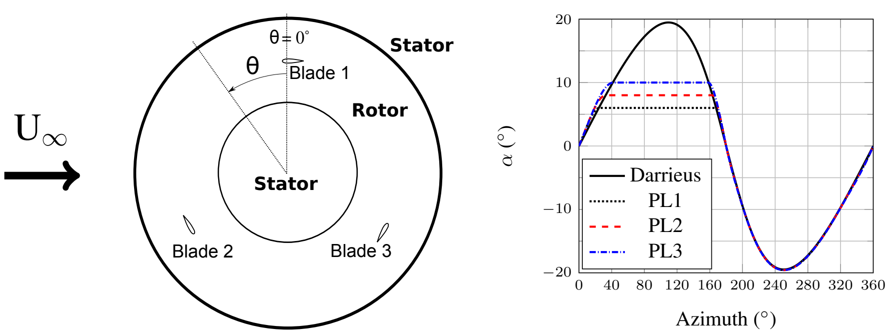

Figure 1: Close view of the computational domain (left) and blades' angle of attack (α) resulting from the pitching laws (right).

Decreasing the angle of attack in the upstream half leads to an increase of the axial velocity at the centre of the

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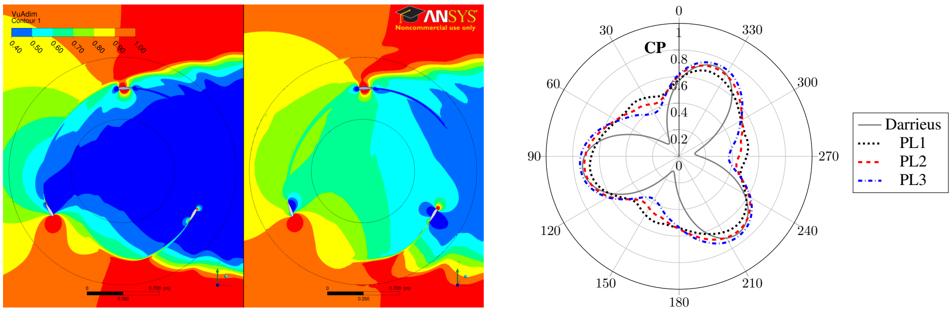

Figure 2: Left: visualisation of axial velocity (U_x / U_∞) in the vicinity of the rotor: left = Darrieus and right = PL2. Right: polar plot of the power coefficient CP.

turbine (Fig. 2, left). The energy available for the downstream half is then higher than in the Darrieus case. It was observed that the blades' tangential force is decreased in the upstream half of the turbine and significantly increased in the downstream half. Variable pitch then leads to a smoother distribution of the CP during one revolution (Fig. 2, right) and to an increase of the average power coefficient up to 35% for the PL2 law. This can be explained by the higher lift to drag ratio at which the blades operate when using variable pitch.

The use of variable pitch for VATT leads to a significant increase of the turbine power coefficient. An interesting feature is that the torque ripple is significantly reduced as well, thanks to a better balance between the upstream and downstream contributions to the torque.

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