Numerical Simulation-Based Performance and Loading Assessment of a Dual-Rotor Ocean Current Turbine Operating in the Florida Straits

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This study demonstrates how a dual-rotor ocean current turbine, equipped with both variable buoyancy and lifting surfaces, can regulate its depth and maintain stable operation in the energy-rich Florida Straits.

Introduction

- Ocean currents along western boundary currents, such as the Florida Straits, present a vast and reliable renewable energy resource.
- Localized energy densities (Fig. 2) exceed 3 kW/m² and are primarily near the sea surface.
- A dual-rotor ocean current turbine (OCT) was developed with variable buoyancy and lifting surfaces (Fig. 1) for depth regulation.
- This project numerically simulates this device, with the basic dimensions in Table 1.

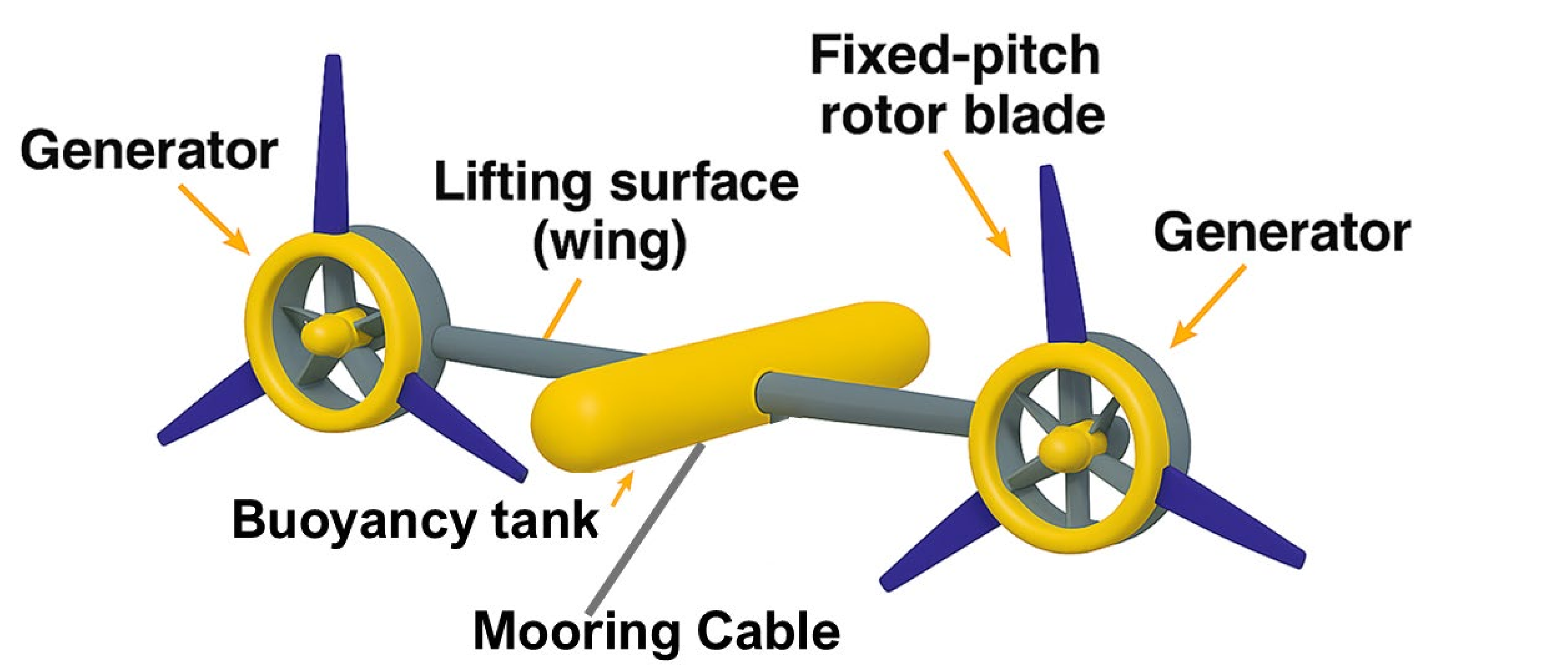

Fig. 1: Schematic diagram of the dual-rotor ocean current turbine.

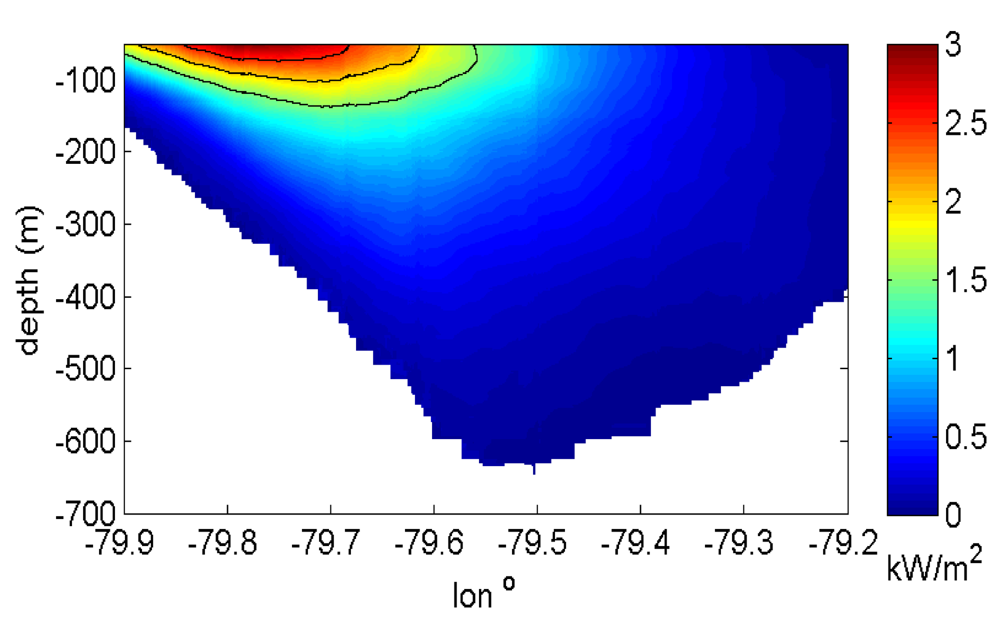

Fig. 2: Average energy density across the Florida Current.

Table 1: Dimensions of OCT system

Dimensions	Value
Buoyancy Tank Length	15 m
Ballast Tank Diameter	2.2 m
Generator Outer Diameter	6 m
Generator Inner Diameter	4 m
Generator Length (front–back)	4 m
Rotor Diameter	20 m
Main Wingspan (each)	15 m
Main Wing Chord	5 m
Cable Diameter	0.16 m
Cable Length	607 m

Numerical Simulation Methodology

- The dual-rotor OCT is modeled as a rigid-body system with 8 degrees of freedom, including 6 DOFs correspond to the translational and rotational motions of the main turbine body in surge, sway, heave, roll, pitch, and yaw.
- The model incorporates the hydrodynamic forces, mooring effects, and realistic actuator behavior.
- Case 1 – Buoyancy Variation: This case investigates the effect of different buoyancy tank fill levels (e.g., 0%, 25%, 50%, 75%, 100%) on turbine performance under a constant flow speed of 1.5 m/s and zero turbulence. The aim is to assess the impact of buoyancy on pitch stability and submersion depth.
- Case 2 – Flow Speed Variation: In this scenario, the system response is evaluated across a range of flow velocities (0.5–3.0 m/s) with fixed buoyancy conditions (50% fill in both front and back tanks) and 10% turbulence intensity. The objective is to analyze the influence of current speed on turbine dynamics and depth and pitch angle trends under passive conditions.
- Simulations are conducted over 20-miniute durations to analyze steady-state and transient performance across different operating conditions.

Dynamic Response Results

A 2-step processed (Fig. 3) was developed to tune the geometry and mass properties of the OCT so that it operates near zero pitch at a depth of 75 meters in a homogeneous current speed of 1.5 m/s when both ballast tanks are 50% filled.

- Wingspan, chord, and static wing pitch angle were systematically adjusted to achieve a force balance between hydrodynamic, hydrostatic, and cable forces using 3DOF (NED) simulation (+ rotor rotation states) to maintain a target depth of 75 meters.
- The mooring cable is attached to the bottom of the buoyancy tank and moved forward/aft to achieve a force and moment balance with zero pitch when running 6DOF (+ rotor rotation states) numerical simulation.
- Resulting system maintains desired pitch and depth for utilized conditions and ballast levels.

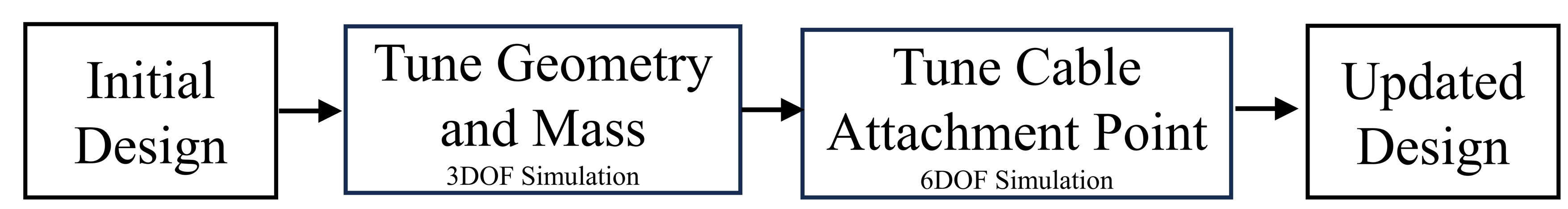

Fig. 3: Block diagram of the component tuning process for the closed-loop control system.

Open-Loop Analysis:

- Case 1 (Fig. 4) evaluates of the effect of buoyancy tank fill variations at a constant flow speed of 1.5 m/s under zero turbulence, to isolate the influence of buoyancy on pitch, and depth.
  - At 50% fill for both tanks, the turbine settles at a final depth of $-75\,m$ with a small pitch angle approximately 0°. Changes in buoyancy levels in both tanks result in significant shifts in depth and pitch, emphasizing the system's sensitivity.
  - With 75% front and 25% back tank fill levels, the turbine reaches a steady-state final depth of $-211\,m$ and maintains a slight nose-down pitch of approximately -6°, eventually. A controller is essential to regulate depth and stabilize pitch under varying fill conditions.
- Case 2 (Fig. 5) evaluates turbine performance at different homogeneous flow speeds (0.5–3.0 m/s) using a fixed buoyancy volume.
  - Reduced flow speed leads to deeper turbine submersion. For instance, at a flow speed of $2.2\ m/s$, the OCT stabilizes at a final depth of about $-25\ m$, whereas at $1.0\ m/s$, it descends to near $-160\ m$.
  - Increased flow speed results in greater pitch angle variations. For example, at a flow speed of $2.2\ m/s$, the OCT settles at a pitch angle of near $+4^{\circ}$, whereas at $1.0\ m/s$, it stabilizes about -3°.

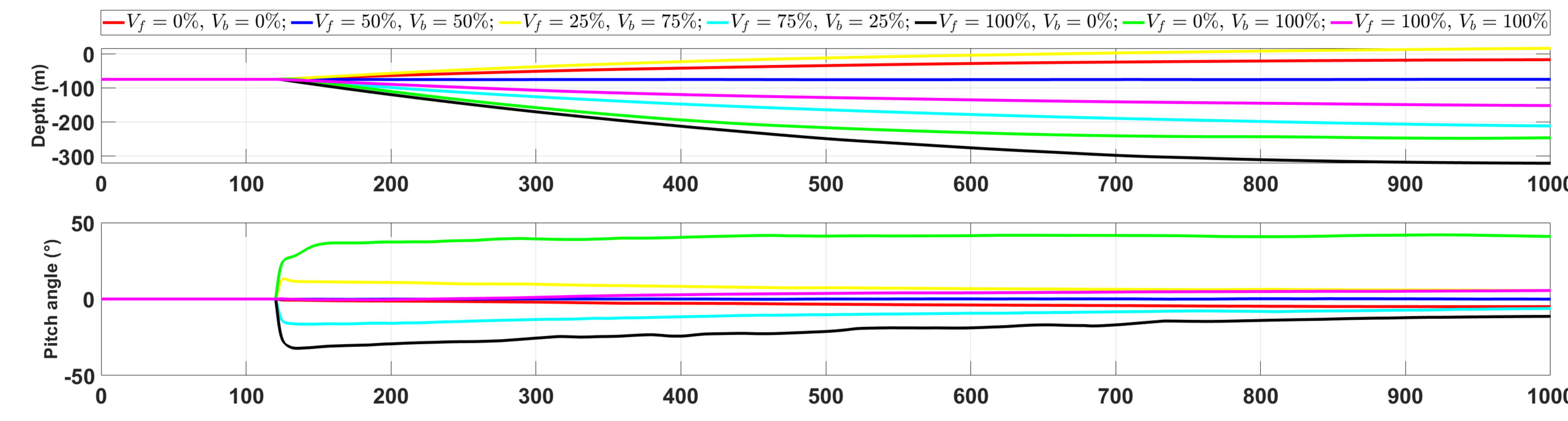

Fig. 4: (Top) OCT (negative) depth [m] and (Bottom) Pitch angle [deg] and for 20-minute open-loop simulations, where ballast tank fill levels are altered after the first 2 minutes.

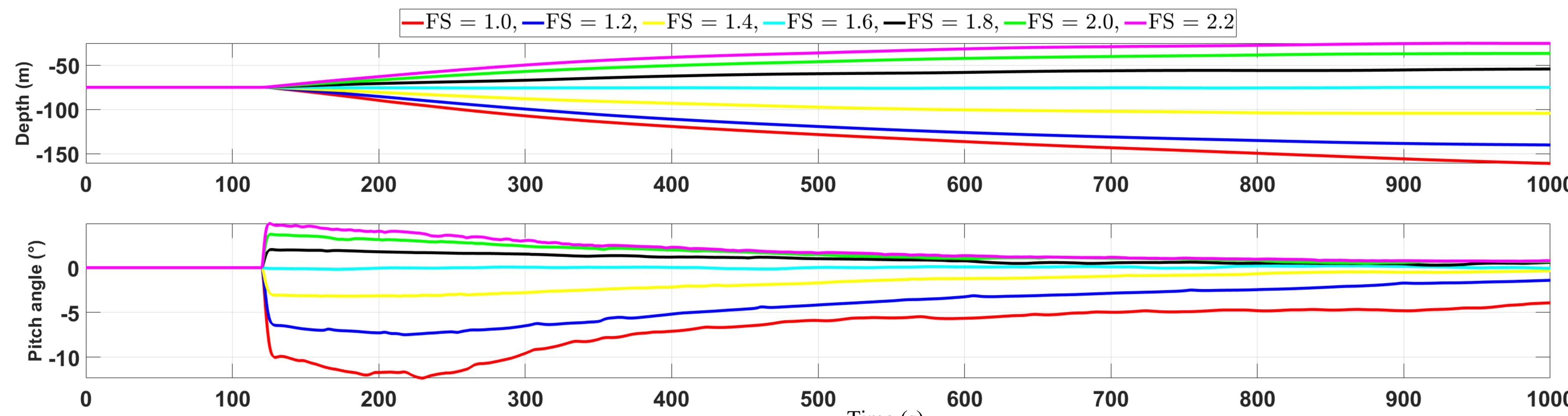

Fig 5. Comparing (Top) OCT (negative) depth [m] and (Bottom) Pitch angle [deg] for 20-minute simulations under varying flow speed profiles. All cases assume identical ballast tank fill levels and a 10% turbulence intensity. Time references the 6-DOF simulation run, which starts at 2 minutes.

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