RAFT: Reconfigurable Array of High-Efficiency Ducted Turbines for Hydrokinetic Energy Harvesting

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Technical Overview: RAFT team

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Th5: Integration & Validation
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Th6: Technology Transfer

*Th: Research Thrust
Technical Overview

- Develop and demonstrate a novel Hydrokinetic Turbines (HKT) concept with:
  - Modularized architecture with reconfigurable arrays;
  - Ducted design for flow conditioning;
  - Folding blades for dislodging debris;
  - Multi-scale and multi-discipline optimization and control co-design (CCD) at micro and macro levels.

- The main objectives of the project:
  - Demonstrate RAFT concepts;
  - Leverage CCD to dramatically reduce LCOE;
  - Develop multi-physics models;
  - Develop design processes and optimization tools.

One Integrated Solution Applicable for Tidal, Riverine, Utility, and Remote Applications
Thrust 1: Hydrodynamic

- Single micro turbine modeling and design optimization:
  - **OpenFoam**: CFD modeling for turbine performance with duct;
  - **DAFoam**: Geometry optimization via adjoint method.

- Macro array modeling and optimization:
  - **Bi-fidelity CFD** model (full geometry vs. body force) for array performance;
  - **Array optimization** via surrogated-based method.

- Macro array modeling and optimization:
  - **FLORIS** to account for wake interactions;
  - Aim for both riverine and tidal environments;
  - **Farm-level** optimization via DRESSA.
Thrust 2: Structural

- **Conceptual design and parametric geometry:**
  - A tool that generates the “wet” or so-called outer-mold-line (OML) geometry of all designs;
  - Visualization and qualitative study of different turbine geometries and array assemblies;
  - Rough estimation of the basic size and mass properties.

- **High-fidelity structural modeling:**
  - FE model for rigid-mounted turbines and turbine arrays;
  - Internal topology design to achieve minimum mass-, transportation-, hydrodynamic-, and generator-induced deformations, and the associated stresses.

- **Low-fidelity structural modeling:**
  - Physics-based models for rigid-mounted and moored-submerged turbines, and turbine arrays;
  - Two-way coupled fluid-structure and generator-structure interactions predictions;
  - System design to minimize mass-, transportation-, hydrodynamic-, and generator-induced deformations, and stresses.
Thrust 3: Electrical

- Achieving high efficiency, high reliability, low cost:
  - Modularized power electronic converters with silicon carbide (SiC) devices and integrated cooling;
    - Less-rated more-efficient cheaper devices,
    - Distributed losses and improved water cooling,
    - Scalable voltages up to medium voltage, less ohmic loss,
    - Smoother power and reduced passive elements,
  - Fault-tolerance and health monitoring;
    - Fault bypass allowing module offline maintenance,
    - Reinforcement learning for condition changes: biofouling,
  - Generator control and control for microgrid connection;
    - Max generator power, min power fluctuation, min stress,
    - Grid-following and grid-forming grid support,
  - Environmental friendliness and adaptation;
    - Minimal electric or magnetic noise emission,
  - Overall electro-mechanical-thermal design optimization.
Thrust 4: System & Control Co-Design

- **Multi-physics modeling and analysis:**
  - Strongly-coupled low-order lumped-parameter multi-physics modeling;
  - Analysis of theoretical bounds for system responses;
  - Theoretical and experimental system identification and validation.

- **Hydrokinetic turbine design optimization:**
  - Leverage OpenMDAO;
  - Modular architecture optimization;
  - Efficient solution of coupled hierarchical models;
  - Efficient computation of coupled derivatives via coupled adjoint method.

- **Control Co-Design and Real-time Control:**
  - Dymos open-source framework built with OpenMDAO;
  - Efficiently computes gradients via an adjoint approach;
  - Control co-design integration with hydro-electro-structural design optimization;
  - Real-time, distributed, and constrained load and power generation optimization via model predictive control (MPC).
Thrust 5: Validation and Demonstration

‣ Integrated system testing at MHL:
  – Physical model basin, 109 m (L), 6.7 m (W), and up to 3.4 m depth;
  – Powered, manned carriage, and an unmanned sub-carriage;
  – Plunging wave-maker for regular and irregular wave generation;
  – Model scale experimental testing and demonstration of the integrated RAFT system (single and multiple units).

‣ Benchtop, wind tunnel, and hydro-environmental testing at Rutgers:
  – Closed-circuit low-speed tunnel with a 71 cm × 51 cm test section;
  – Fully automated Eiffel type tunnel with max flow speed of 72 m/s;
  – Motion capture and high-sensitivity load cells for automated benchtop experiments;
  – Hydraulic, wave, and sediment flume, volumetric hydraulic benches.

‣ Electrical system testing at WESRF
  – 750 kVA dedicated utility power;
  – Multiple rotary test beds up to 300 hp;
  – Multi-physics energy storage banks;
  – Medium-voltage high-power power supplies.
Path to Target LCOE

Key RAFT Contributions | LCOE, M1, and M2 Variables Affected
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Reconfigurability and Modularity | Water turbine availability, Structure manufacturing, OpEx/kW
Control co-design and Power regulator | Max. power coefficient, Resilience and robustness
Elimination/reduction of floating/mooring system, as well as tower/cross-arm/columns | Mass reduction
Less number of drive train components | Drive-train losses, Mass reduction, OpEx/kW, Turbine availability

Key T0 (environmental) activities:
- **Filtering** of debris and marine species, **dislodging** of entangled species, and **bio-fouling cleaning** through duct inlet screen, and **folding blades**;
- **Alleviating noise** and vibration through electrical module design and system control;
- **Assessing marine animal collision** risks, and physical impact on environmental flow conditions, sediment transport.
Project Impact

- **Innovations and Transformational Impacts**
  - **Modularized** architecture with **reconfigurable** units:
    - Significant reduction in LCOE, CapEx, and OpEx;
  - **Scalable** design **adaptable** to river-bed/sea-floor topographies;
  - **Control co-design** enabling **resilient** operation in the harsh marine environment:
    - Multi-disciplinary optimization to exploit synergies between physical and control design spaces;
  - **Distributed load control** for optimal power production:
    - Innovative differential control for active yaw and pitch control of the array assembly,
    - Leveraging the environmental condition and coordination among RAFT units.

*TSR: tip speed ratio*
Tech to Market Plan

- **Design Cases:**
  - One integrated solution applicable for S1, S2, S3, and S4 (tidal, riverine, remote, utility);
  - Focus on S2 and S3 (tidal/remote, riverine/utility);
  - Adoption of moored-submerged type of RAFT for ocean current.

- **Target Stakeholders/Market:**
  - Renewable and offshore energy industry;
  - Suppliers and the US government.

- **T2M Barriers:**
  - No pre-existing commercialization partner(s);
  - Manufacturing and supply chain for HKT.

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Reconfigurable Micro-Turbine as building blocks

Removal of key barriers for T2M (fabrication, manufacturing, CapEx, OpEx, ...)

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ASSESS DEVELOP UNLEASH MARKET ANALYSIS ADVANCE TECHNOLOGY REDUCE RISK LICENSE

FELLOWS REPORT PROTECTION FEEDBACK PARTNER SELECTION AGREEMENT MANAGEMENT

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Preliminary T2M Plan, Value proposition, Key stakeholder, IP management, Competitive landscape, Scale-up, Follow-up funding, Formal T2M Plan, Update 1 of T2M Plan, Update 2 of T2M Plan, Update 3 of T2M Plan, Update 4 of T2M Plan, Final T2M & Pitch Plan
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