Design and Path Planning of a Marine Hydrokinetic Turbine to Power Blue Economy

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Introduction

Marine renewable energy (MRE) can reduce reliance on fossil fuels and improving energy security while accelerating progress in the blue economy.

Different applications of MRE to power blue economy [1]

- Autonomous underwater vehicle charging
- Fish farming and offshore aquaculture
- Water desalinization
- Disaster area
- Ocean observation
- Resilient community, etc.

Figure 1: Marine Renewable Energy Resources [1]

To harness high power potential in **U.S. ocean current (49 TWh/year)** [2]

↓

Design a marine hydrokinetic (MHK) turbine

Highlights

- Design a 700-kW buoyancy-controlled MHK turbine
- Verify performance of the designed MHK turbine by numerical simulation
- Propose a path planning for MHK turbine to maximize harnessed power and showing its importance compared to a static operation.

Turbine Modeling and Path Control

A 700-kW **buoyancy-controlled** MHK turbine is designed for operation in the Gulf Stream off the Florida's East Coast, which follows the prototype systems from IHI Corp. [3].

The ocean power is **depth dependent**, so a spatiotemporal path planning is proposed to maximize electricity generation.

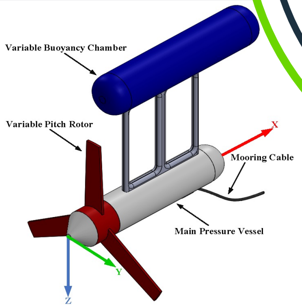

Figure 2: Schematic of our MHK

Equations of Motion (EOM)

$$f_x = m^v(\dot{u} - vr + wq) - m^v x_{cg}(q^2 + r^2) + m_b^v z_{cgb}^v(p_b r + \dot{q})$$

$$f_y = m^v(\dot{v} + ur) - w(m_b^v p_b + m_r^v p_r) + m_b^v z_{cgb}^v(q_r + \dot{p}_b) + m_b^v x_{cgb}^v q p_b + m_r^v x_{cgr}^v q p_r + m^v x_{cg}^v \dot{r}$$

$$f_z = m^v(\dot{w} - uq) + v(m_b^v p_b + m_r^v p_r) + m_b^v z_{cgb}^v(p_b^2 + q^2) + m_b^v x_{cgb}^v r p_b + m_r^v x_{cgr}^v r p_r + m^v x_{cg}^v \dot{q}$$

$$M_{xb} + M_{xr} = -m_b^v z_{cgb}^v(\dot{v} - w p_b + ur) + I_{xr}^v \dot{p}_r + qr(I_{zr}^v - I_{yr}^v)$$

$$M_y = I_y^v \dot{q} + r p_b(I_{xb}^v - I_{zb}^v) + r p_r(I_{xr}^v - I_{zr}^v) + I_{xzb}^v(p_b^2 - r^2) + m_b^v z_{cgb}^v(\dot{u} - vr + wq) - m^v x_{cg}^v(\dot{w} - uq) + m_b^v x_{cgb}^v v p_b - m_r^v x_{cgr}^v v p_r$$

$$M_z = I_z^v \dot{r} + q p_b(I_{yb}^v - I_{xb}^v) + q p_r(I_{yr}^v - I_{xr}^v) + I_{xzb}^v(rq - \dot{p}_b) + m_b^v x_{cg}^v(\dot{v} + ur) - m^v x_{cg}^v(\dot{v} + ur) - m_b^v x_{cgb}^v w p_b - m_r^v x_{cgr}^v w p_r$$

$$\dot{p}_r = \frac{M_{xr} - M_{xz} - qr(I_{zr}^v - I_{yr}^v)}{I_{xr}^v}$$

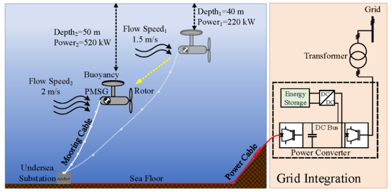

Figure 3: Schematic of MHK path planning

Simulation Results for Designed MHK Turbine

To assess operation of MHK, the ocean current is modeled with real measured data by Acoustic Doppler current Profiler (ADCP) from Gulf Stream of Florida [3].

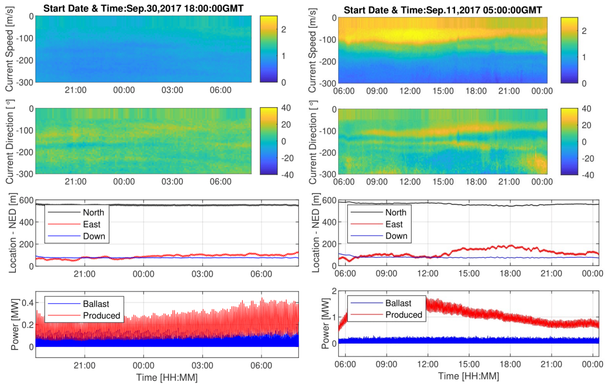

Figure 4: MHK performance under Left: normal condition (Oct. 1, 2017); Right: hurricane condition (Sep. 11, 2017)

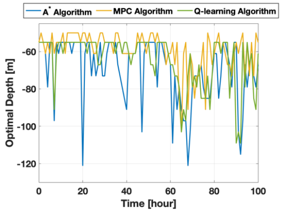

Figure 5: Optimal path for MHK turbine

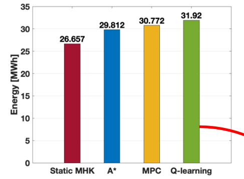

Figure 6: Comparison harnessed energy

Evaluating three approaches for path planning in a 100-hour period:

- Static MHK: Baseline
- A* algorithm: +11.8 %
- Model predictive control: +15.4 %
- **Q-learning algorithm: +19.7 %**

Conclusion

A buoyancy-controlled MHK turbine is designed and numerically simulated in an ocean environment modeled by real-recorded data from Gulf stream of Florida. For the designed MHK turbine, path planning is proposed to harness maximum power.

Future Work

1. Validate the MHK performance for real turbine in a realistic environment.
2. Present the spatiotemporal path planning for the MHK array.

References

[1] https://www.nrel.gov.

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[3] T. Ueno, S. Nagaya, M. Shimizu, H. Saito, S. Murata, and N. Handa,"Development and demonstration test for floating type ocean current turbine system conducted in kuroshio current," in 2018 OCEANS-MTS/IEEE Kobe Techno-Oceans (OTO), pp. 1–6, IEEE, 2018.

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