Adaptive Control of In-Stream Ocean Current Turbines for Load Reduction

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DISTINCTION THROUGH DISCOVERY
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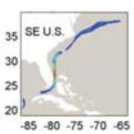
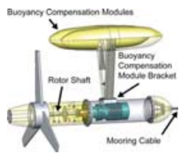
Introduction

- Ocean current energy is one of the many renewable energy resources available to us with an estimated 5.6 GW of theoretical electrical power in the Florida Straits alone. This resource has an average kinetic energy flux that reaches 3.3 kW/m² [1] and can be harnessed by the use of ocean current turbines (OCT).
- OCT's typically operate in three distinct regions. Region 1 is the startup where the turbine turns on. Region 2 is when power production starts. Region 3 is when rated power is produced. The scope of this study is Region 2 operation.
- As the three bladed OCT operates, the blades experience varying cyclic axial loads (bending moments) due to various current speeds caused by current shear.





Method

- An adaptive algorithm to individually pitch the blades called Direct Adaptive Disturbance Rejection (DADR) is implemented in order to reduce the change in bending moment in order to keep the loadings constant irrespective of their blade positions.
- This algorithm calculates the adaptive gains by utilizing d-q axis transformation borrowed from the three phase electrical machine theory and calculates the controlled outputs using the following basis functions [2],

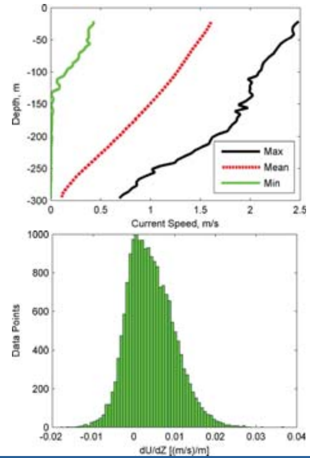
$$[u_3\ u_2\ u_1] = [G_1 \quad G_2]\begin{bmatrix} \sin(\theta) & \sin\left(\theta+\frac{2\pi}{3}\right) & \sin\left(\theta+\frac{4\pi}{3}\right) \\ \cos(\theta) & \cos\left(\theta+\frac{2\pi}{3}\right) & \cos\left(\theta+\frac{4\pi}{3}\right) \end{bmatrix}$$

- Here u_3, u_2, and u_1 are the individual blade pitches of blades 3, 2, and 1. G_1 and G_2 are the adaptive gains which are calculated using the following,

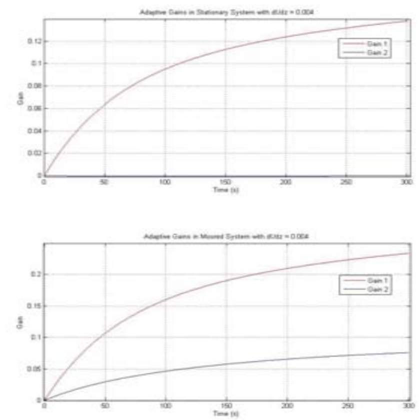
$$\begin{bmatrix} \dot{G}_1 \\ \dot{G}_2 \end{bmatrix} = -\left[\frac{2}{3}\begin{bmatrix} \cos(\theta) & \cos\left(\theta+\frac{2\pi}{3}\right) & \cos\left(\theta+\frac{4\pi}{3}\right) \\ \sin(\theta) & \sin\left(\theta+\frac{2\pi}{3}\right) & \sin\left(\theta+\frac{4\pi}{3}\right) \end{bmatrix}\begin{bmatrix} M_3 \\ M_2 \\ M_1 \end{bmatrix}\right]\gamma_D$$

- Here θ is the rotor azimuth angle, M_3, M_2, and M_1 are the measured moments, and Y_D is a positive scalar that can be used to modify the convergence rate of the adaptive controller gains.

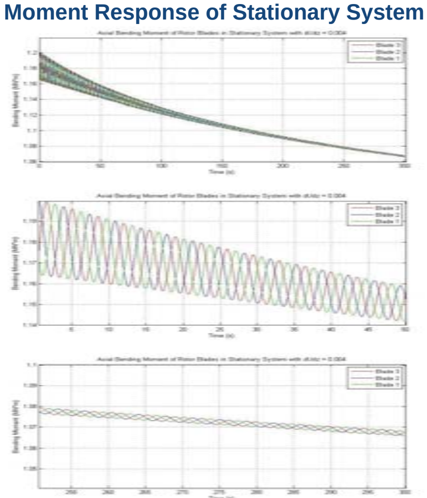
Average Current Speed and Current Shear in the Florida Straits



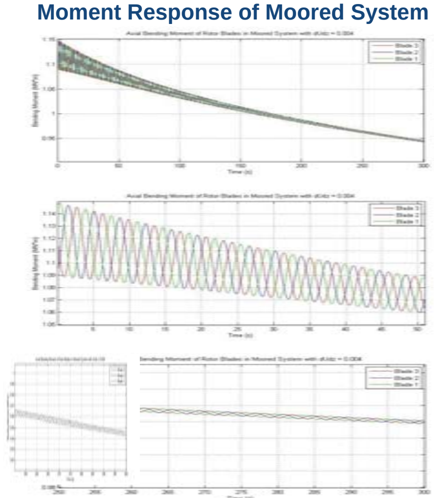
Gain Convergence of Stationary and Moored Systems



Moment Response of Stationary System



Moment Response of Moored System



Results

1. The simulations run for 300 seconds for both the stationary and moored system with the turbine operating in equilibrium conditions in stationary and moored configurations.
2. The simulation uses a turbine depth of 30m, a surface current speed of 1.72 m/s, and a current shear of 0.004 (m/s)/m in order to maintain a mean current speed of 1.6 m/s at the hub depth as shown in the average ocean current data to the left [3].
   - In the stationary system, the varying moment is reduced from 0.034 MN*m within the first 1.67% of simulation run time to 0.003 MN*m in the last 1.67% of run time, showing a 91.18% reduction in moment amplitude. The adaptive gains G_1 and G_2 converge to approximate values of 0.12 and 0, respectively.
   - The moored system shows that the loads are reduced from 0.061 MN*m to 0.004 MN*m from the first and last 1.67% of simulation run time which yields a 92.3% reduction in moment amplitude. The adaptive gains G_1 and G_2 converge to approximately 0.228 and 0.058.

Discussion

1. Both the stationary and moored systems show evidence of load reduction due to the adaptive controller.
2. The controller shows increased performance for the moored system as opposed to the stationary system.
3. Future research can expand on the work presented here to increase power production with the adaptive controller by optimizing the RPM while operating in Region 3.

References

1. M. C. P. M. Machado, J. H. VanZwieten, and I. Pinos, "A Measurement-Based Analysis of the Hydrokinetic Energy in the Gulf Stream," Journal of Ocean and Wind Energy, vol. 3, no. 1, pp. 25-30, Feb. 2016.
2. Bossanyi EA , 2003 "Individual blade pitch control for load reduction," Wind Energy 6: 119–128
3. J.H. VanZwieten, N. Vanrietvelde, and B. Hacker, 2013 "Numerical Simulation of an Experimental Ocean Current Turbine," IEEE Journal of Oceanic Engineering, vol. 38, no. 1, pp. 131-143.

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