Adaptive Torque Control of In-Stream Hydrokinetic Turbines

Juan Diego Ramirez
Florida Atlantic University, Boca Raton, FL, USA, jramir56@fau.edu

Faculty Mentor:
James H. VanZwieten Jr., PhD
Florida Atlantic University, Boca Raton, FL, USA, jvanzwi@fau.edu

ABSTRACT

This work focuses on improving the power production of in-stream hydrokinetic turbines by implementing an adaptive controller that regulates shaft torque. The research quantifies increased energy production by comparing the power production when standard fixed-gain and adaptive gain torque regulating controllers are utilized. This project was done at the Southeast National Marine Renewable Energy Center at Florida Atlantic University as a Honors Directed Independent Study for the Innovation Leadership Honors Program.

1. INTRODUCTION

Diversifying US energy production to include renewable resources has been a popular topic of discussion recently. In-stream hydrokinetic energy, electricity produced from moving currents without the use of dams, has potential for significant power production with feasible US electricity production estimated at 14 GW from rivers, 50 GW from tides, and 19 GW from ocean currents; accounting for approximately 17 % of US power production.

1.1 PROBLEM

The efficiency of power generation has always been a topic of concern. The objective of this research is to quantify potential energy gain by implementing adaptive torque control compared to fixed-gain control using numerical models to simulate the systems.

1.2 BACKGROUND

Ocean current turbines have been researched for many years but only a few small scale devices have been installed. Most in-stream hydrokinetic energy devices use rotors attached to a generator to produce power. Research has shown that regulating torque to achieve a constant rotational velocity allows the turbine to achieve optimal power production.

2. APPROACH

The system used for testing the control algorithms for this project was the Southeast National Marine Renewable Energy Center experimental ocean current turbine.

2.1 NUMERICAL MODEL

The utilized numerical hydrodynamic rotor model is configured to model the 3 meter diameter rotor presented in (VanZwieten et al., 2013). It was designed using mathematical models created in the MATLAB/Simulink environment. The rotor is modeled as a single rigid body and hydrodynamic forces are estimated using a blade element momentum approach with a dynamic wake inflow model.

2.2 FIXED GAIN CONTROL ALGORITHM

This torque regulating controller calculates applied electromechanical generator torque according to

$$\tau = K\omega^2 \qquad \text{Eq. 1}$$

where ω is the rotor rotational velocity in rad/s and K is a fixed gain for which optimal performance should be calculated by

$$K = \tfrac{1}{2} (\rho A R^3 C_{p,max})/\lambda^3. \qquad \text{Eq. 2}$$

In Equation 2, $C_{p,max}$ is the maximum power coefficient and λ is the corresponding tip speed ratio (TSR). The optimal gain is found only when using the correct maximum power coefficient and the tip speed ratio that actually yields that value.

2.3 ADAPTIVE GAIN CONTROL ALGORITHM

The adaptive controller was designed to converge an estimate of the controller gain K used in Equation 1 towards its optimal value, thus increasing power production. The controller calculates the regulated generator torque according to:

$$\tau = M\omega^2 \quad \text{Eq. 3}$$

where M is the adaptive gain which is calculated using an average of previous values by

$$M(k) = M(k-n) + \Delta M(k) \quad \text{Eq. 4}$$

$$\Delta M(k) = \gamma\rho \operatorname{sgn}[\Delta M(k-n)]\operatorname{sgn}[\Delta Pavg(k)]|Pavg|^{\wedge}½. \quad \text{Eq. 5}$$

In Equation 4 and 5, n is the period of time over which the power coefficient is averaged and Pavg is the averaged power coefficient value. This adaptive torque control method was presented in (Johnson, 2004).

3. RESULTS

Both controllers were developed and simulated with the hydrodynamic rotor model to compare the power production of the system with the different controllers.

3.1 FIXED GAIN CONTROLLER PERFORMANCE

This model calculated the maximum power coefficient to be 0.46, which is achieved when the TSR is 3.95. To quantify the relationship between estimated power coefficient values and the estimated TSR at which the maximum power coefficient occurs, numerical simulations were run using a matrix of maximum power coefficient and tip-speed ratio combinations with Figure 1 showing the resulting average power production. The lines showing the actual maximum power coefficient and its corresponding tip speed ratio are presented in this figure as a reference. The optimal K value of 104.4 was shown to produce an average power output of 7.2 kW.

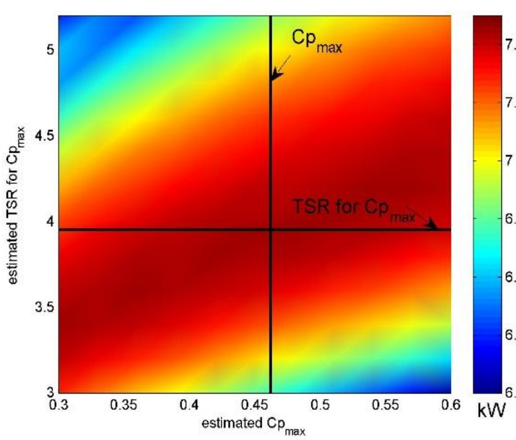

Figure 1: Average power produced by turbine with fixed gain controller based on a range of estimated maximum power coefficient and tip speed ratio values.

3.2 ADAPTIVE GAIN CONTROLLER PERFORMANCE

This controller is evaluated using the numerical rotor simulation and was shown to converge an initial K estimate of 55 to near its optimal value in approximately 7 hours. As the gain converges to its optimal value, the rotational velocity of the turbine converges toward a value of 38 RPM, which for the evaluated flow speed correspond to the optimal TSR of 3.95. During this time the average power produced converges from an initial value of 7 kW to a maximum value of 7.2 kW, as shown in Figure 2.

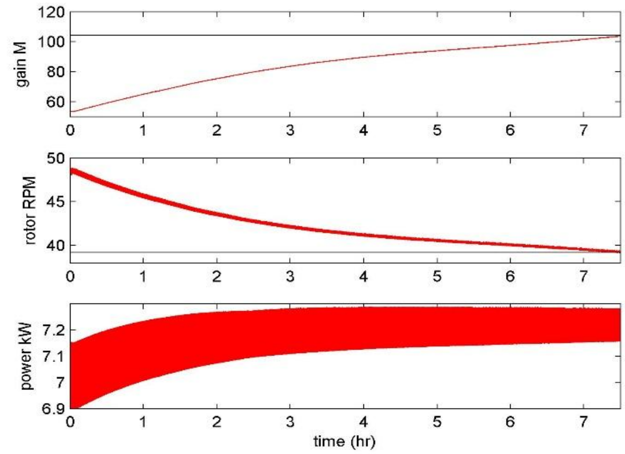

Figure 2: Average power produced by turbine with adaptive controller

4. CONCLUSION

By comparing these controllers we have quantified the effect that inaccurate estimates of turbine characteristics can have on the power production of a hydrokinetic turbine, and demonstrated a methodology for tuning controller gains so that near optimal performance is obtained. The conducted numerical simulations demonstrated that adaptive control can effectively converge a sub-optimal controller gain to an optimal one that maximizes shaft power using only measured RPM and flow speed values. We concluded that the fixed gain controller will allow the turbine to generate optimal power only if the maximum power coefficient and tip speed ratio values are estimated correctly which would depend on full knowledge of the turbine characteristics. The adaptive controller adjusts its gain to achieve optimal power by itself, with the drawback being added complexity and the need to measure flow speed.

REFERENCES

James H. VanZwieten, Nicolas Vanrietvelde, and Basil Hacker (2013) “Numerical Simulation of an Experimental Ocean Current Turbine,” IEEE Journal of Oceanic Engineering, vol. 38, no. 1, pp. 131-143

Kathryn E. Johnson (2004) “Adaptive Torque Control of Variable Speed Wind Turbines,” Technical Report, National Renewable Energy Laboratory, NREL/TP-500-36265

Authorization and Disclaimer

Authors authorize LACCEI to publish the paper in the conference proceedings. Neither LACCEI nor the editors are responsible either for the content or for the implications of what is expressed in the paper.