Control of an Open-Source Tidal Energy Converter (OSTEC) Testbed

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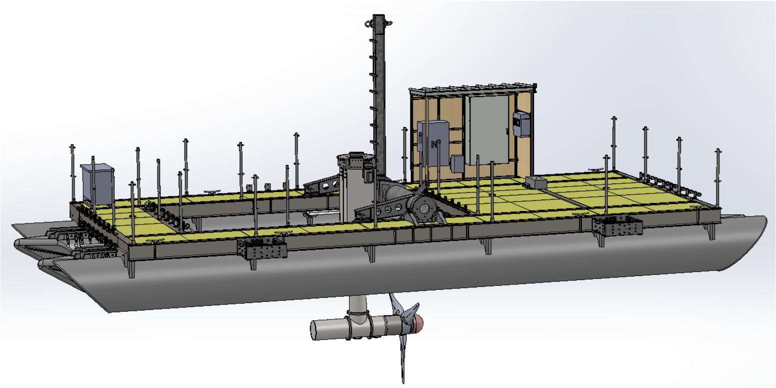
General Motivation

Overarching

- ❖ Design, build & deploy an instrumented axial flow tidal turbine
- ❖ Operation in a real tidal flow
- ❖ Turbine size allows scale-up of results (to utility scale)
- ❖ Provide public open- source data sets
- ❖ Comprehensive model verification and validation (V&V)
  - ➢ Digital twinning
  - ➢ Numerical models
- ❖ Provide feedback on marine energy IEC standards
- ❖ The Turbine:
  - ➢ 3-bladed axial flow device based on the MHKF1 hydrofoils
  - ➢ Rotor diameter of 2.5 meter,
  - ➢ 26 kW generator power
  - ➢ Deploy at UNH-AMEC Tidal Energy Test Site, Memorial Bridge, Portsmouth, NH
  - ➢ Tidal current speed over 2.5 m/s



OSTEC

Open-Source Tidal Energy Converter

A highly instrumented test bed for scalable R&D and technology demonstrations at an energetic tidal energy test site.

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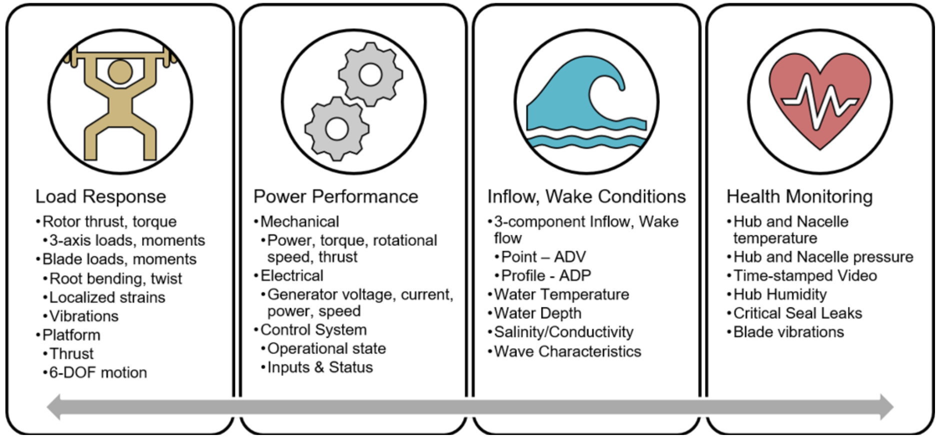
WATER POWER TECHNOLOGIES OFFICE

General Motivation

Research Goals

- Help marine energy industry make progress (technology ramp)
- Time synchronized data collection
  - Power performance
  - Mechanical & design loads
  - Tidal inflow conditions
  - Health monitoring
- Effect of turbulence structures on tidal turbine performance & loads
- Dynamics of powertrain of axial flow tidal turbine
- Heat transfer analysis of the tidal turbine system



Why study controls?

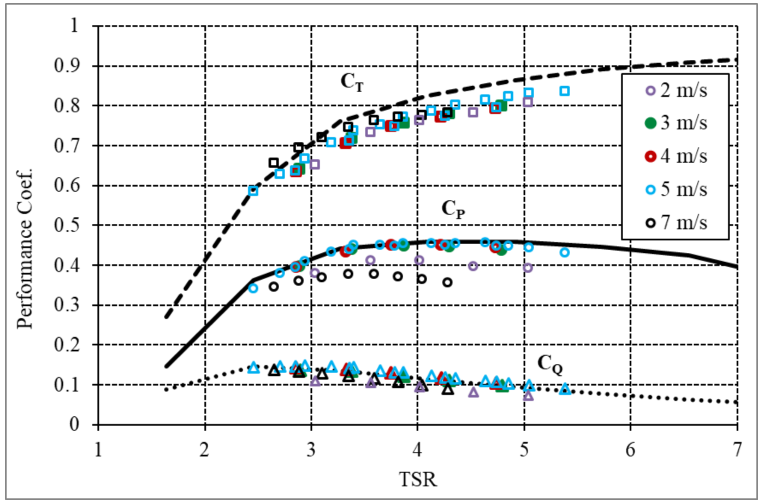
Motivation

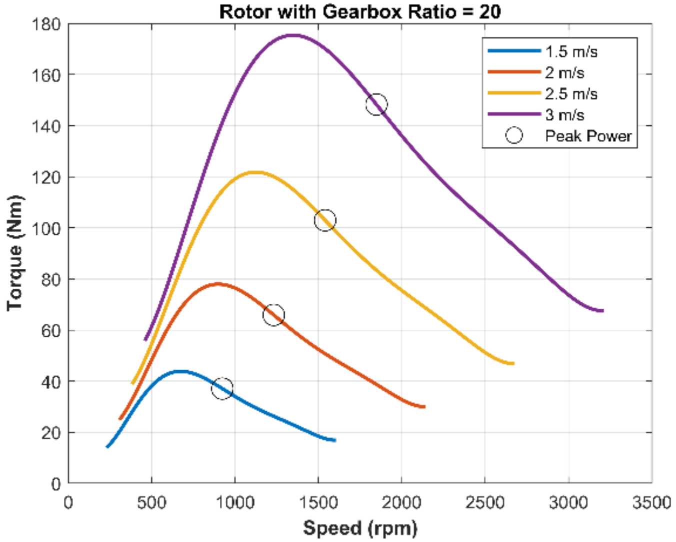
- Tidal turbines operate in predictable but variable flow conditions,
  - With bi-directional currents
  - High fluid density (seawater ~800x denser than air).
- This affects:
  - Torque magnitude (depending on the size of the machine)
  - Inertia and load dynamics
  - Control objectives (e.g., bi-directional efficiency)
  - Larger added mass in water than air (affect rotor dynamics)
- Tidal turbines progress toward commercialization
- Control strategies becomes crucial for optimized efficiency
- Essential for dynamic performance modeling and analysis of tidal turbine components
  - Turbine response time to turbulence timescales
  - Provide critical insights to optimum control strategy

Definitions

Performance Characteristics

Power curves for OSTEC

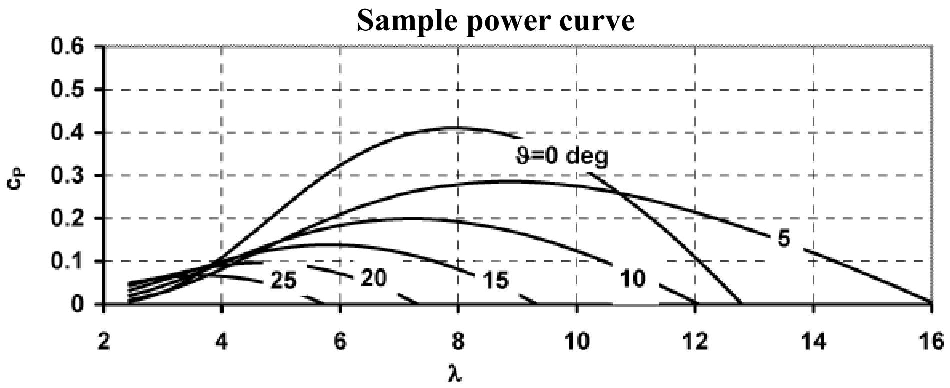




Due to the shape of the performance curve, peak power occurs at an rpm higher than peak torque.

Definitions

Performance Characteristics



Analytical approximation of $C_p(\lambda,\theta)$ characteristics

Power Coefficient $[C_p]$

$$C_p = \frac{T\omega}{\frac{1}{2}\rho A U_\infty^3}$$

Tip Speed Ratio $[\lambda]$

$$\lambda = \frac{R\omega}{U_\infty}$$

Parameter	Definition	Unit
R	Rotor radius	m
ω	Rotor rotational speed	RPM
T	Hydrodynamic torque	N.m
ρ	Fluid density	kg/m^3
A	Rotor area	m^2
U_∞	Inflow velocity	m/s

- Maximum Power Point Tracking (MPPT), a common approach for controlling TEC's:
  - A control scheme designed to maximize energy extraction.
  - MPPT identifies and maintains the optimal operating point using:
    - Real-time measurements of rotational speed
    - Power output
    - Inflow velocity

Simply, MPPT seeks the maximum Cp on the power curve

Definitions

Control Schemes

	Speed control	Torque control
Objective:	Maintain optimal rotor speed for maximum power extraction	Control generator torque to match optimal Cp curve
Method:	Adjust generator torque	Direct based on inflow condition
Advantages:	Avoiding overspeed (mechanical stress)	Control power output
Limitations:	May struggle with sudden change in flow (high turbulent)	Vulnerable to overspeed Require accurate modeling and real time data
OSTEC:	Current state	Future work

Equations

$$\tau_{gen} = K\omega^2$$

$$K = \frac{1}{2}\rho A R^3 \frac{C_{p_{\max}}}{\lambda_*^3}$$

Constant Gain Control Implementation

computing a value for K from a single characteristic maximum power point corresponding to a known velocity using K* equation

$$K^* = \frac{1}{2}\rho A R^3 \frac{[0.273U_\infty - 0.068]}{[0.920U_\infty + 0.645]^3}$$

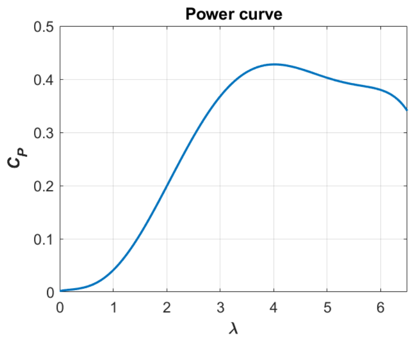
Dynamic Turbine Model

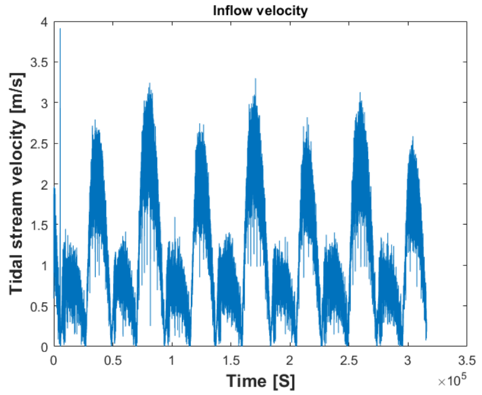
Numerical Simulation

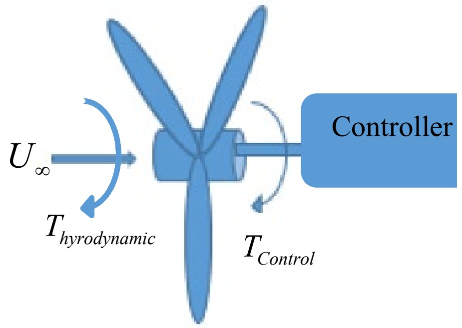
Initial Model

$$\dot{\omega} = \frac{(T - T_c)}{J}$$

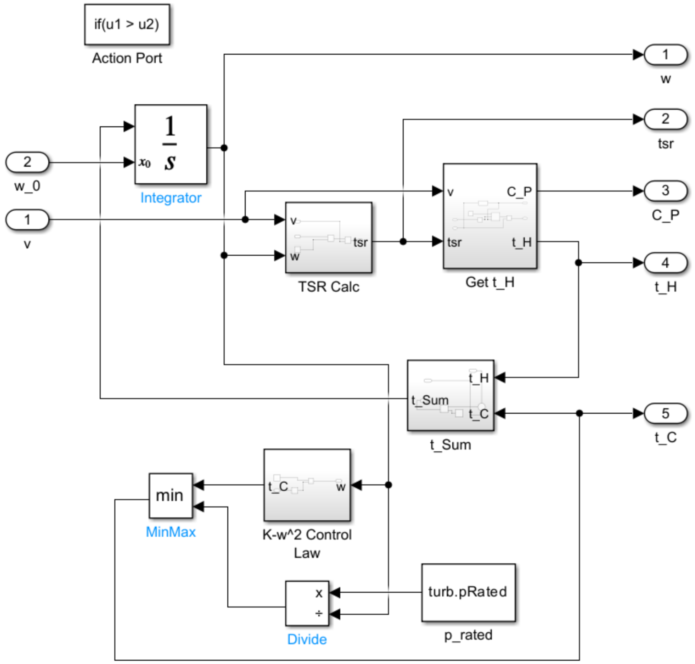
$$\omega_{i+1} = \omega_i + \dot{\omega}\Delta t$$



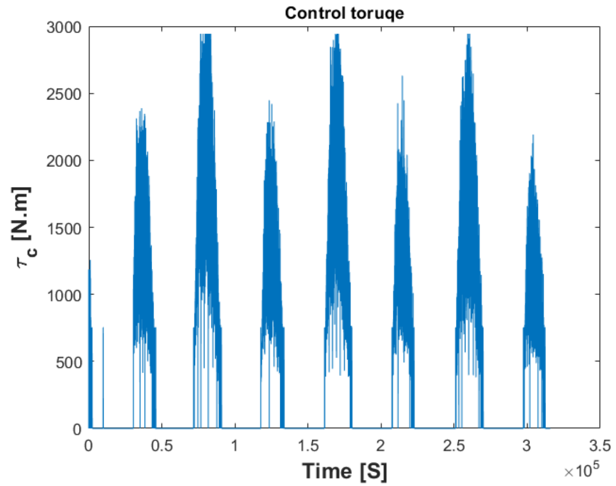




Simulink Model



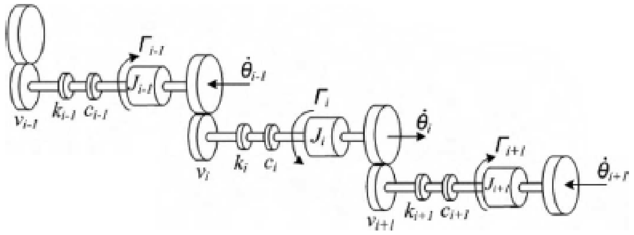
Initial Model Result



Dynamic Turbine Model

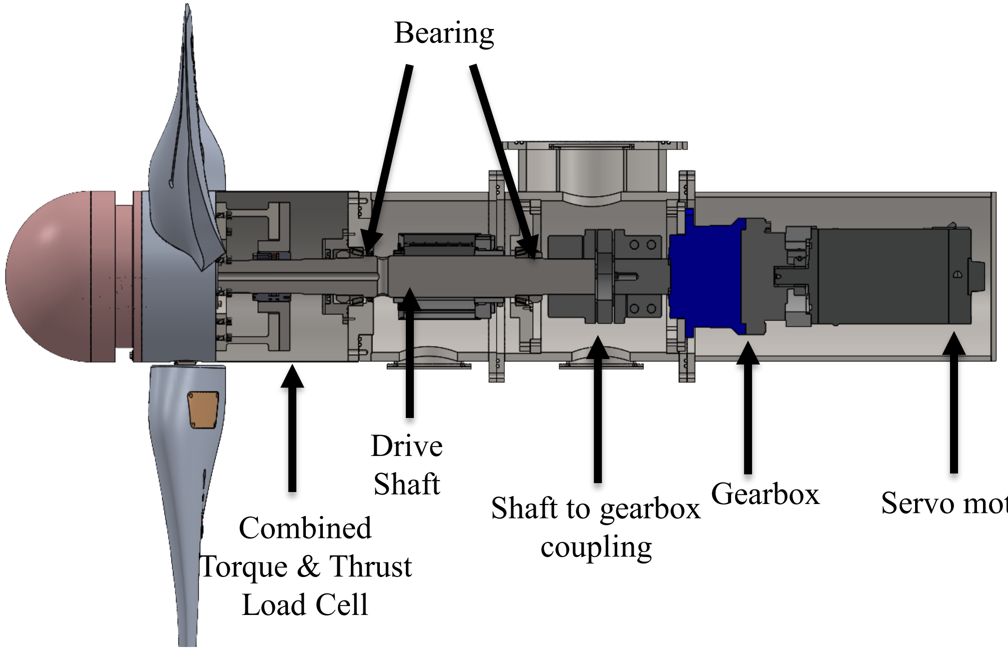
On going work

- Implementation of spring- mass model for mechanical parts including drive shaft, bearings, and gearbox
- Direct effect on system stiffness and response time
- More accurate control scheme simulation
- More accurate angular moment of inertia (J)



Discrete spring- mass model for drive train

Developing Model



Turbine Control

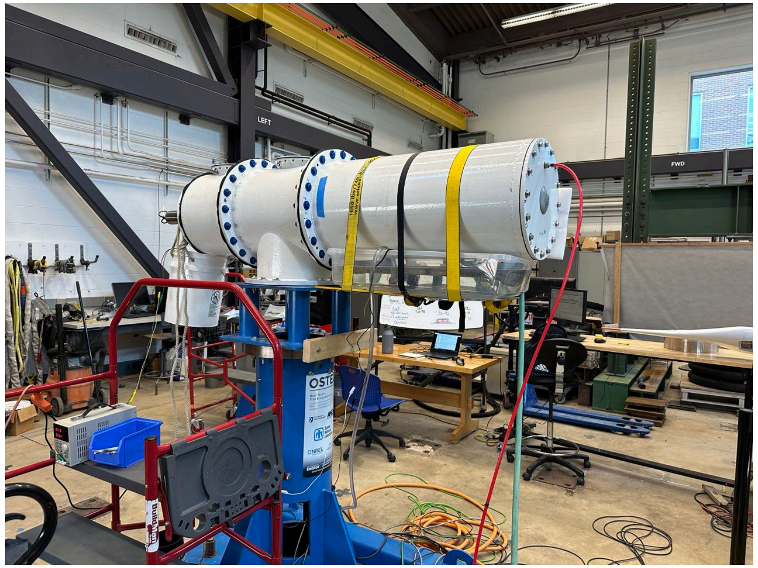
Current state and future work

Current state of OSTEC

- System integration and dry testing (final steps)
- Control system integration with data acquisition system
- In-lab turbine baseline data

Future work

- Validate the control simulation results with the OSTEC deployment data for
  - Speed control
  - Torque control
- Compare the simulation result with actual measurements on System stiffness and response time to the turbulent inflow conditions
- Add more fidelity by modeling other complicated mechanical components like generator



OSTEC turbine

OSTEC Rotor

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- **Funded by U.S. Department of Energy’s Water Power Technologies Office**
- **In Collaboration With**

  Sandia National Laboratories (SNL)*, National Renewable Energy Laboratory (NREL), Pacific Northwest, National Laboratory (PNNL)

*** This work is supported by the U.S. Department of Energy’s Office of Energy Efficiency and Renewable Energy (EERE) through the Water Power Technologies Office (WPTO). Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy’s National Nuclear Security Administration under contract DE-NA0003525.**

Thank You

Questions