ORPC Autonomous Turbine Generator

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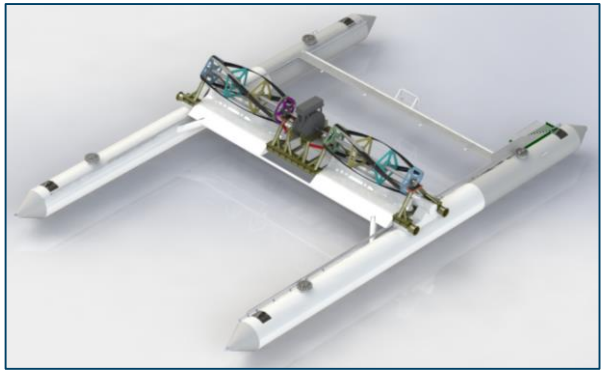
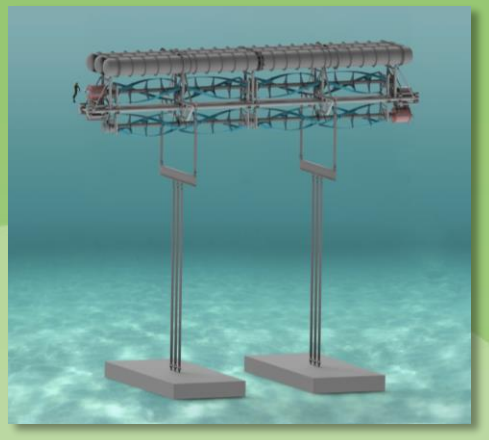
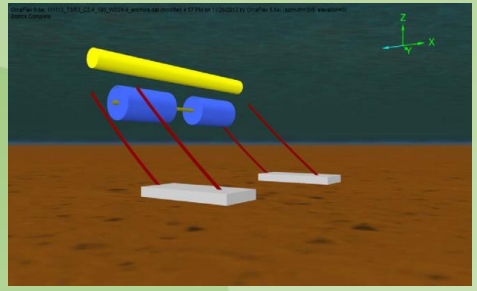
TidGen® (2012)

RivGen® (2015)







Buoyant-Tension-Leg Mooring System significantly reduces installation costs for deep water systems.

Cost Drivers for Tidal Projects

- Tidal is much more expensive today than wind
  - Primary cost drivers are capital expense of marine materials
  - OpEx cost of marine operations
    - Cost of working on/in the water is >> than on land
      - Weather, daylight, heavy lift de-rating, tides, etc.
  - Maturity of the technology
    - Reliability
    - Design standards

2012 - TGU deployed onto bottom support frame (BSF), both installed using barge-mounted crane

2013- Catamaran retrieval of TGU from BSF

- Need a low cost O&M strategy
  - Either never do maintenance
  - Or make accessibility less expensive

Autonomous TGU (ATGU) Rationale

- Operations and maintenance at sea:
  - Existing methods are expensive.
  - Marine assets are limited at many sites.
  - Restrictions occur based on weather, sea state and daylight.

- Pitching foils can:
  - Improve power generation efficiency Vector thrust
  - Generate large thrust loads

- Pitching foils on a TGU could allow it to self-propel to a deployment site!

Example of pitching foils for propulsion: twin Voith Schneider propellers with thrust plate on a tug's hull

Technology Summary

• Develop an innovative deployment and retrieval system for an MHK power system using computational models for variable pitch to analyze forces and maximize energy extraction in operation mode for cross-flow turbines

•Develop design and cost analysis of the full scale, commercial system with active pitch control propulsor concept

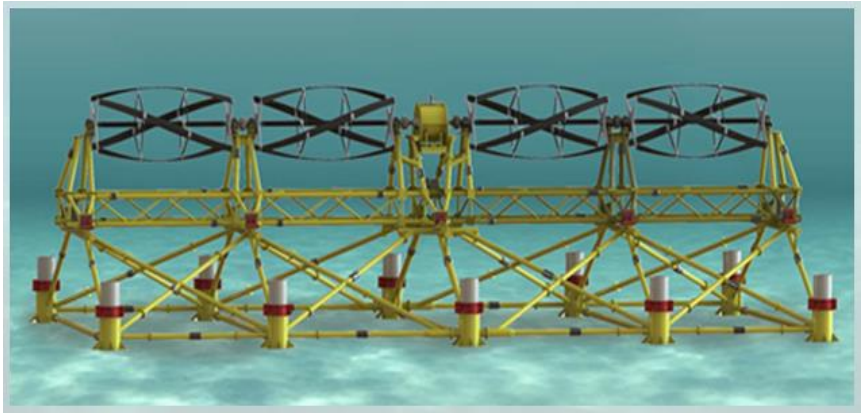
Technology Impact

•Drastically reduces O&M costs

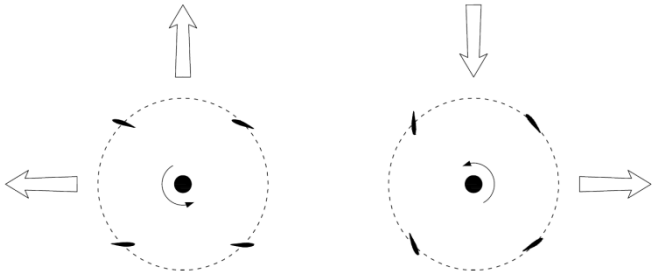
•Dramatically improves efficiency of electricity generation

•Significantly reduces LCOE

Self-deploying MHK device is completely disruptive; offers very large reductions in O&M costs; slashes LCOE



Rendering of the ORPC grid-connected TidGen® tidal turbine, a marine hydrokinetic power system for which ORPC proposes a self-deployment and retrieval system.



Effect of implementing Co-Control Concepts

- Reductions in the O&M Expenses for a typical MHK project by a factor of 10
  - No more standing costs for support vessels
  - Much smaller crew req'd
  - Operation windows increased
- Increase energy generation efficiency by 50%
  - Pitching foils keep flow attached
- Cut LCOE by factor of 2
  - Improved AEP and decreased O&M
  - Capital costs increase somewhat

But Wait……

- We are proposing to develop a system that is different from what we normally do
  - *Isn't this just the combination of two bad ideas?*
  - *How do we justify this change of focus for a company*
  - *We are already developing a acceptable product*
  - *Is it worth the effort?*
  - *Etc, etc*

- These thoughts are all examples of the mental gymnastics required to follow through on a radical concept
  - *Need to be prepared to make changes to the system concept*
    - *Even though there has a lot of time/money/effort invested in the prior design*

- Revisiting prior work can be *Difficult* but it is *Necessary* to take advantage of a features offered by new concept

Power System Re-Envisioned
- some things will be obvious from the start

- Pitch control is required for the turbine foils
  - Controls can be implemented by
    - Turbine RPM control for each turbine
    - Foil Pitch amplitude control
    - Foil Phase control

- Generator
  - Each turbine or turbine pair should have its own generator
  - Smaller generator
  - Torque requirements for propulsion outweigh requirements for power generation
  - Drive electronics required for propulsion & generation
  - Controls required for both modes

Some things will develop with time

- Turbine foil
  - Straight rather than helical
  - Provides the opportunity to taper the chord more efficiently
  - Lower manufacturing cost
    - Different manufacturing methods – extrude?
  - The number of controls available is much larger than originally anticipated
    - Good or bad?
- Sensors
  - System should know “where it is”
  - What does autonomy really mean?

Some things take time to realize

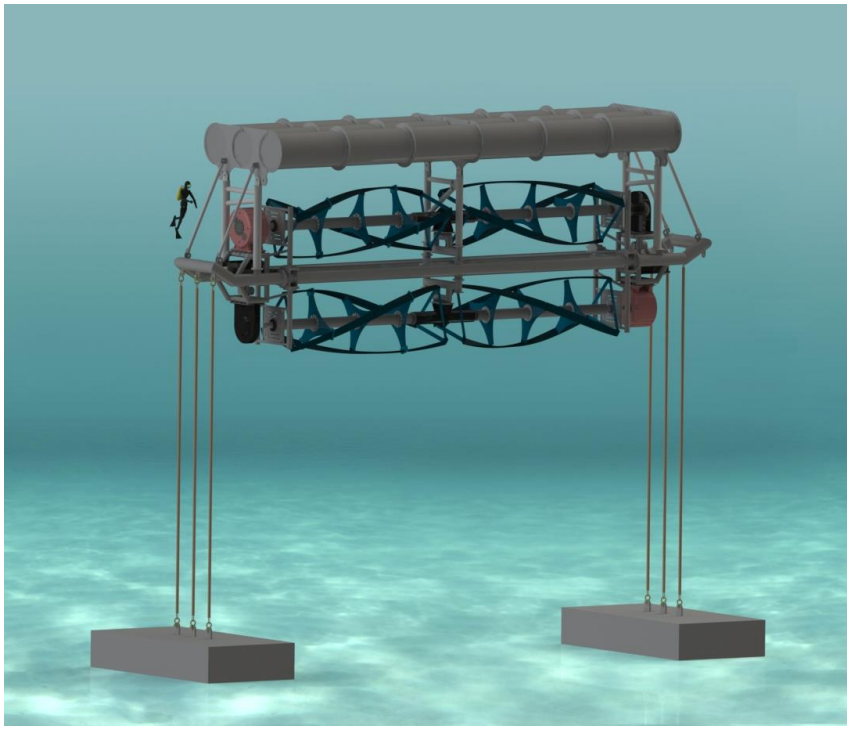
- We have spent a lot of time looking at the shape of the buoyancy pod
  - Selected the span wise shape for multiple reasons
    - Primary reason was shape of deployment vessel
    - System towed in the low drag direction
  - Invested a lot of effort, ego, $, in the design
  - Learned a lot about how it behaved

- Woops – we don't need it anymore
  - System self deploys
  - Torpedo shapes have less drag
  - System propels itself

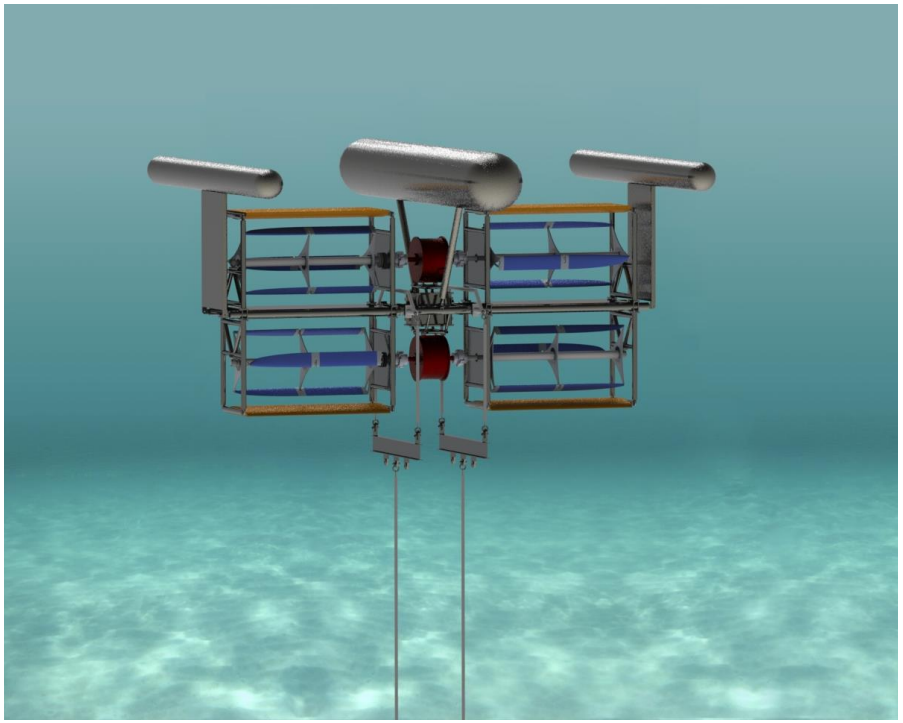
- *It took a surprisingly long time to get over our own biases in favor of what would be a better solution*

Some things will take time to work through

100kW TidGen® Design



100kW ATGU® Design



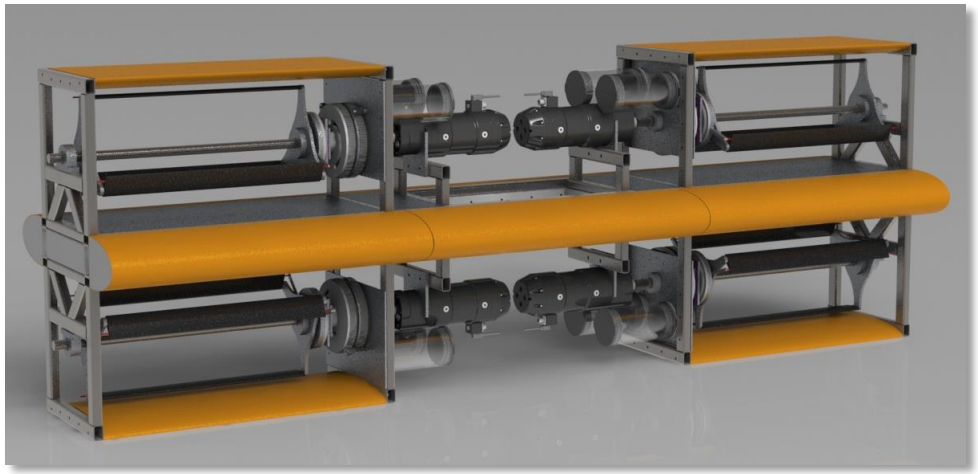
Product also evolves….

- As part of the project we wanted to build a scale model to test
  - The scale model will be affected by Reynolds number
  - Therefore we should build as big a scale model as feasible

- As we began to build up the design for the model we thought
  - Hey …that looks interesting. We could use that.
    - Inspection system (ROV)
    - Instrumentation deployment
    - Geotechnical work
    - Subsea power networks

- The model scale is its own product line

Small Scale Demonstrator (SSD) Specifications



Dimensions	1.4 m x 3.9 m x 1.0 m
Dry Weight	850 kg
Generation at 2 knots/4 knots/6 knots	400 W/3.2 kW/10.9 kW
Max Thrust at 5 knots	> 6,000 N (600 kg buoyant)
Battery	80 kWh (2 hour life at 100% thrust)

Depending on orientation, device can generate lifts up to 20 kN (CFD) while holding position in 5-knot current

What's interesting to me…

- Cognitive dissonance is going to happen
- Lateral thinking is needed
- Preconceptions need to be re-examined all the way through the project
- Outcomes are not so predictable

What the future holds for MHK

- River systems
  - Definitely believe cross-flow turbines are better in rivers due to effects of blockage
- Ocean Currents
  - Tethered large scale systems are probably the future of baseload Utility MHK systems
  - Flying TGUs
    - Like flying underwater windkites
    - Added complexity in controls!

End