Applications for a Swivel-based Mooring System that Improves System Reliability for Marine Energy Devices

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A slip ring-swivel system that addresses axial loading on and rotation of electric/power cables and fluid hoses and has broad applications to marine energy devices.

INTRODUCTION

Motivation:

- Ocean testing trials have demonstrated challenges with damage to ME cables (Fig. 1) which can cause the ME device to fail.
- Two major modes of failure are high axial loads from varying sea states and line twisting due to the ME device motion.

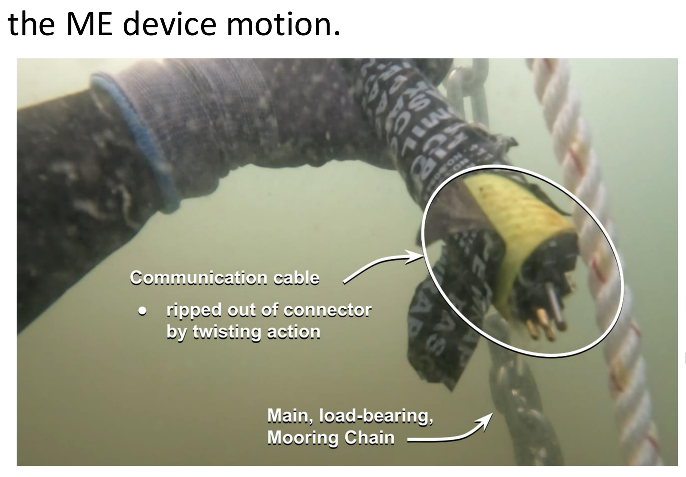


Fig. 1: *Damaged wave energy converter (WEC) cable from twisting of the mooring line.*

Conceptual Design & Prototype:

- We are developing a slip ring-swivel system which passes fluid filled hoses and power/communication cables (Fig. 2).
- Three major elements of the slip ring-swivel system are the slip ring (rotational motion - electrical), rotary union (rotational motion - fluid), and spring/damper (axial loading).

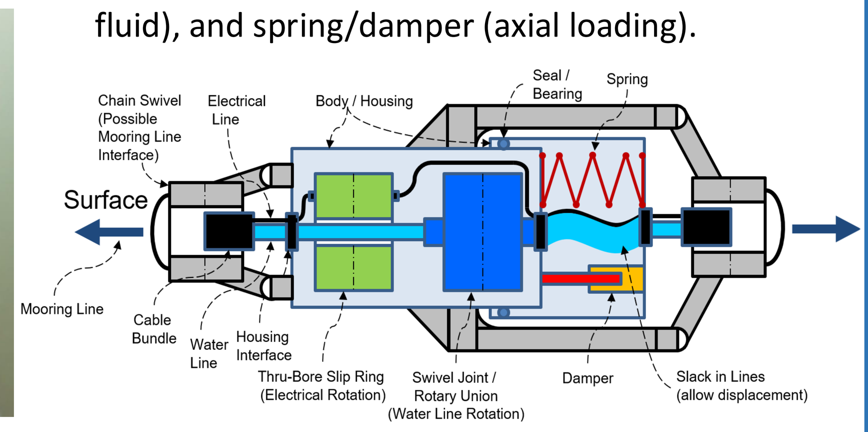


Fig. 2: *Slip ring-swivel system preliminary design.*

NC's MARINE ENERGY RESOURCE

Wave Energy Resource:

- Wave periods are generally between 4-10 s, while significant wave heights are largely 0-2 m (Fig. 3).
- NC's wave energy resource has led to developing the Jennette's Pier Wave Energy Test Center for ocean testing.

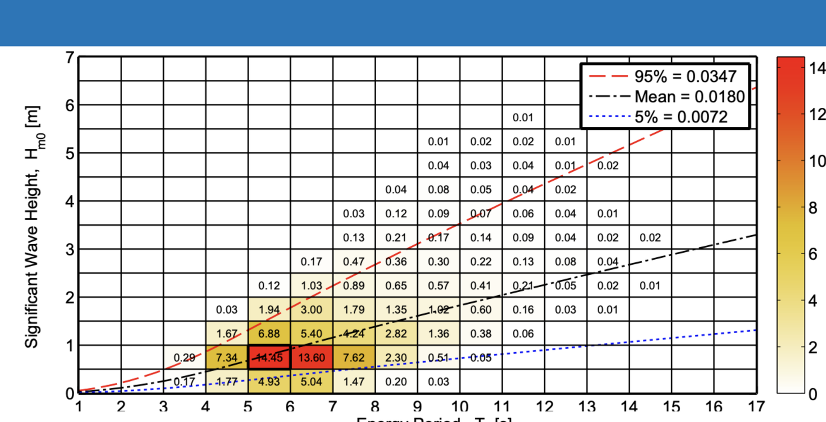


Fig. 3: *Joint probability distribution of sea state at Jennette's Pier based on NREL's wave hindcast. Figure is from [1].*

Current Energy Resource:

- NC's proximity to the Gulf Stream results in flows that reach 2.5 m/s (Fig. 4).
- These high speeds extend down hundreds of meters, but the lateral position of the Gulf Stream varies in time.

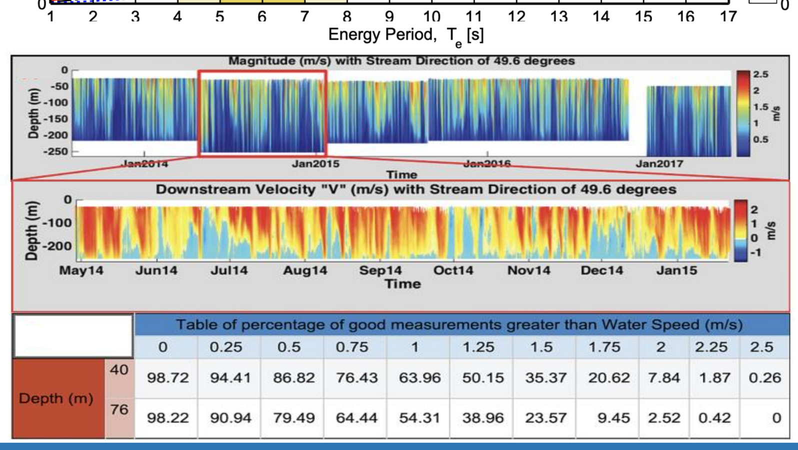


Fig. 4: *In-situ measurements of ocean velocity with percent occurrence of speed bins. Figure is from [2].*

NC's MARINE ENERGY APPLICATIONS

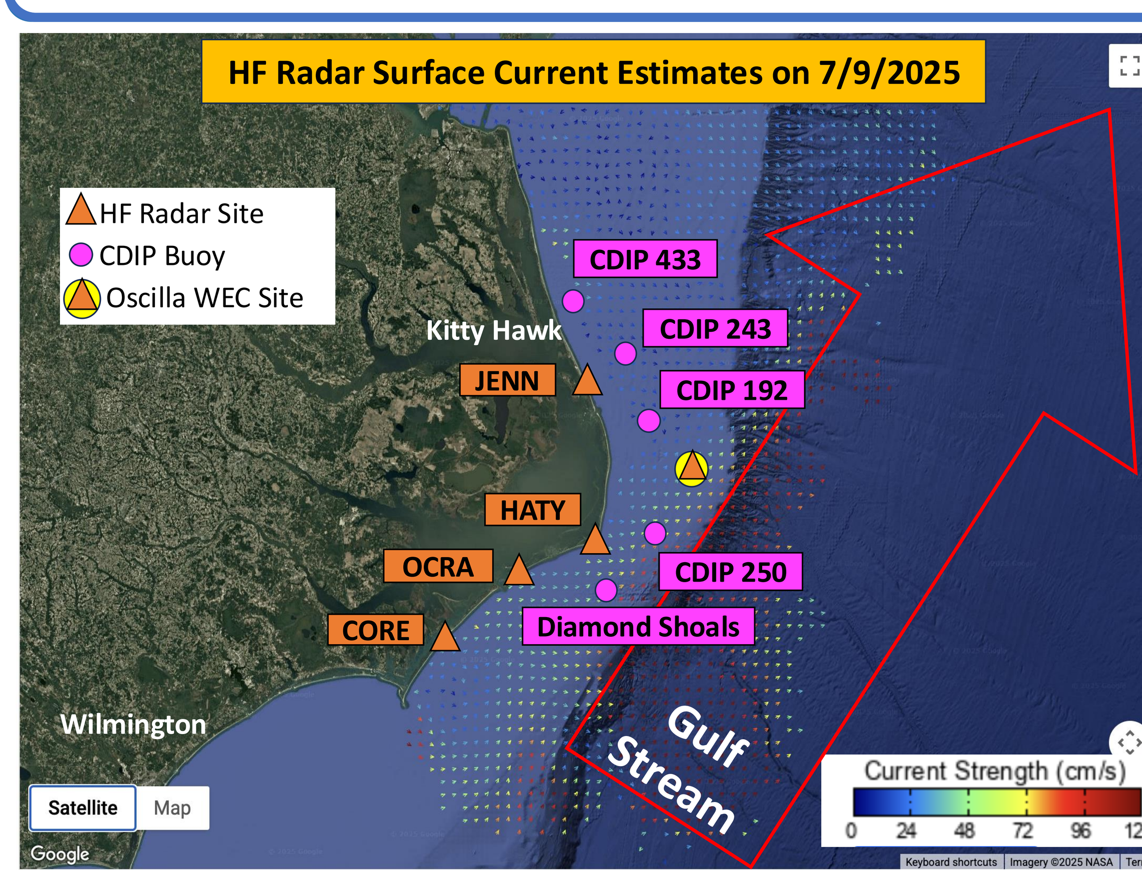


Fig. 5: *HF radar surface currents overlaid with HF radar locations, wave buoy locations, and schematic arrow representing the Gulf Stream offshore location (not to scale).*

Examples of potential ME applications in NC's coastal ocean. Such possible ME applications could integrate the slip ring-swivel system.

High-Frequency (HF) Radars:

- Oscilla Power WEC to power Codar HF radar antenna to expand HF radar network (Figs. 5-6) of surface current measurements over Gulf Stream – DOE SBIR funded project between Oscilla, Codar, and Coastal Studies Institute.

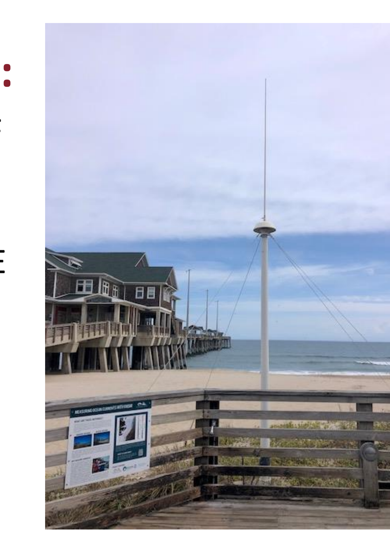


Fig. 6: *HF radar antenna at Jennette's Pier.*

Wave and Weather Buoys:

- NDBC/CDIP buoys (Fig. 5) collect meteorological and oceanographic measurements and buoy swaps are dictated by battery life remaining.
- Additional sensor payloads (e.g., ocean currents) will increase buoy power demand.
- NSF Ocean Observatories Initiative (OOI) Coastal Pioneer array deployed off Nags Head in spring 2024 (Fig. 7).

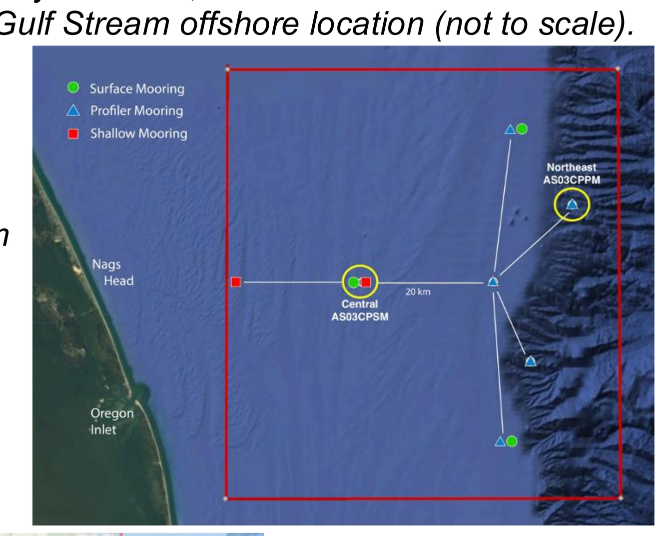


Fig. 7: *NSF OOI Coastal Pioneer Array off Nags Head, figure from [3].*

Offshore Wind Environmental Monitoring:

- Offshore wind lease blocks off Kitty Hawk and Wilmington (Fig. 8).
- Companies leasing Wilmington blocks have/will be conducting environmental monitoring and thus instruments will have power needs.

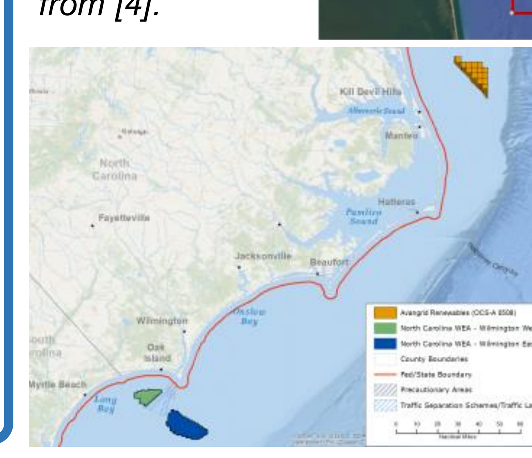


Fig. 8: *NC offshore wind leases, figure from [4].*

Aquaculture:

- NC's aquaculture market includes oysters, soft shells, clams, and finfish. Electricity demands (e.g., lighting, pumps, aeration, etc.) from this industry could be supported by ME devices with strategic marine spatial planning.

Remotely Powered Sites:

- Former US Navy light towers off NC are privately operated and are remote systems that require on-site power (Fig. 9).
- These isolated towers require both electricity and provisions and could benefit from renewable ME and drinkable water.

Fig. 9: *Frying Pan tower, figure from [5].*

TECHNICAL CHALLENGES

- Marine environments are dynamic and corrosive making ocean technology survivability a challenge.
- Cyclical loading causes fatigue while storms can produce inhospitable sea states. The slip ring-swivel system must operate or withstand limit states associated with such phenomena.
- Seawater corrosion can cause technology failures and impact its integrity over time. Additionally, material selection must not incur galvanic corrosion.
- Biofouling can grow on ocean technologies which can render functionality and performance.

FAILURE MODE AND EFFECTS ANALYSIS

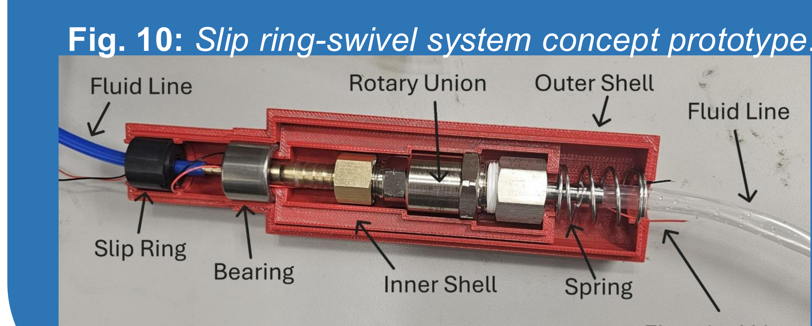
Item/Function	Potential Failure Mode	Potential Effects of Failure	Severity (1–10)	Potential Causes	Occurrence (1–10)	Current Controls	Detection (1–10)	RPN (S×O×D)	Recommended Actions
Rotary Union	Leaking water	Water contacting electrical components, corroding connection and housing	3	Seal wear, improper assembly	3	Visual inspections, pressure test, high qualtiy hardware purchased	3	27	Create routine testing schedule, Add pressure sensor
Slip Ring	Short-circuit	Failure to tramsmit power, shorting to enclosure and could transmit large electrical shock to WEC inproperly.	4	Worn brushes, improper assembly	3	Visual inspection of brushes, using multimeter to check for continuity across device	2	24	Create routine testing schedule, Add insulation around slip ring to isolate device from enclosure
Internal fluid hoses	Leaking water	Water contacting electrical components, corroding connection and housing	3	Improper assembly causing kinks in line, manufacturer defects.	1	Visual inspection of hoses and connections should obviously reveal faults.	1	3	Create routine testing schedule
NPT Barbs - Rotary Union	Leaking water	Water contacting electrical components, corroding connection and housing	3	Manufacturer defects, improper installation, not torqued tight enough, insuffecent thread sealant	3	Visual inspection while transmitting fluid should reveal any defects,	1	9	Create routine testing schedule, research marine-grade thread-sealing methods
Sealing interface between individual enclosure pieces	Leaking salt water into enclosure	Corrosive salt water could damage polymeric hoses and wire shielding, causing unexpected fluid leaks and electrical shorts from slip ring if it is not water resistant. Seawater leakage could also introduce aquatic life and other biofouling into enclosure if leakage occurs.	4	Improper installation, improper sealant medium for conditions	1	Seal should be replaced after any disassembly once device is exposed to a corrosive environment. Fault detection once installed may not be possible.	5	20	Create routine testing schedule, research gasket material
Enclosure corrosion	Leaking salt water into enclosure or enclosure breaking away from securing fixtures	Corrosive salt water could damage polymeric hoses and wire shielding, causing unexpected fluid leaks and electrical shorts from slip ring if it is not water resistant. Seawater leakage could also introduce aquatic life and other biofouling into enclosure if leakage occurs.	4	Insufficient enclosure material corrosion resistance	3	Visual inspection of enclosure when removed from corrosive environment may show obvious signs of corrosion, depending on the rate at which enclosure material corrodes. Exact state of enclosure corrosion resistivity may be hard to determine from visual inspection alone - additional testing may be required.	4	48	Create routine testing/inspection schedule

Severity		Occurence		Detection	
Rating	Definition	Rating	Definition	Rating	Definition
1	Fault in component will not result in any lasting damage to component or others.	1	Component is from a reputable source and made from quality materials. Failure should not occur under expected conditions.	1	Any faults should appear obvious in routine testing. Standard test procedure already in place, or will be simple to conduct.
2	Fault in component could result in permament damage to component.	2	[redacted]	2	Faults should appear obvious in routine testing, but a standard test procedure is not in place.
3	Fault in component could result in permenant damage to component and surrounding components in enclosure.	3	Component is from a reputable source, but quality of individual component is not known.	3	Some faults may appear obvious in routine testing, but others may not. More rigerous testing and inspection may need to occur to detect all possible faults.
4	Fault in component could result in permenant damage to all components and enclosure.	4	[redacted]	4	Faults may not readily appear in simple routine testing, extensive routine testing required to find faults.
5	Fault in component could result in permenant damage to all components, entire enclosure, and surrounding entities.	5	Quality of source and component is not known	5	Component shall require extensive routine testing where faults will remain difficult to detect.

NEXT STEPS

- Develop functional prototype that demonstrates axial loading and rotation.
- Conduct dry testing of functional prototype.
- Integrate a sensor package for health monitoring (e.g., axial loading, rotation, and flow rate measurements).

Fig. 10: *Slip ring-swivel system concept prototype.*



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