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Berkeley Lab Comments - CEC 23-ERDD-01 RFI Entangled Debris Monitoring for Floating Offshore Wind Infrastructure

Please see comments attached.

Additional submitted attachment is included below.

September 13th, 2024

Jonah Steinbuck
Director of the Energy Research and Development Division
California Energy Commission
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Re: Lawrence Berkeley National Laboratory Comments CEC RFI Entangled Debris Monitoring for Floating Offshore Wind Infrastructure (Docket # 23-ERDD-01)

Director Jonah Steinbuck,

Berkeley Lab is pleased to present our comments in response to the California Energy Commission's Request for Information regarding Entangled Debris Monitoring for Floating Offshore Wind Infrastructure.

Question #1: What technologies, equipment, and types of inspection could detect entanglement on FOSW infrastructure? What research is needed to advance these technologies? Please provide details on sensor accuracy, potential cost of the technology, and any additional hazards or conditions that can be detected/monitored.

Distributed Fiber Optic Sensing (DFOS) technology, specifically distributed acoustic sensing (DAS) and distributed strain sensing (DSS), offers a powerful solution for detecting entanglement on Floating Offshore Wind (FOSW) infrastructure, e.g. Mooring lines. Monitoring of mooring lines in its entirety that can extend more than 1000 meters is a significant challenge as there is a critical need to detect events anywhere on the structure with the ability to locate them and assess their impacts precisely. DFOS systems use optical fibers as sensors embedded in or attached to the structure, enabling the measurement of vibration, strain, and other physical changes with high spatial resolution down to millimeters and high sensitivity. These sensors are capable of continuously monitoring the entire length of the structure in real time, providing precise data that can detect entanglement events and locations, such as fishing gear or marine debris interaction, by identifying unusual strain patterns or vibrations indicative of external interference.

Sensor Accuracy and Cost: DFOS technology is highly accurate, with the capability to detect microstrain levels and identify changes with spatial resolution as fine as a few millimeters, providing a level of detail that far surpasses traditional sensors. The cost of DFOS systems can vary, typically ranging from $20,000 to $200,000 depending on the type of signals measured, complexity of the deployment, the length of the fiber, and the associated data acquisition equipment. However, these costs can be offset by the reduction in manual inspections and the ability to perform continuous monitoring in harsh offshore environments.

Detection of Additional Hazards: Beyond entanglement, DFOS can monitor a wide range of conditions on FOSW platforms, including structural integrity (strain, fatigue, and crack propagation), real-time vibration analysis, temperature variations, and environmental impacts such as underwater acoustics from marine traffic or the presence of marine life, e.g.

whales. This multi-functional capability enhances the safety and reliability of the infrastructure, and promotes environmental sustainability.

Research Needs: Advancing DFOS for FOSW entanglement detection requires research in optimal sensor integration with the structures, signal processing algorithms to enhance the identification of specific entanglement patterns, the development of robust fiber coatings to withstand harsh marine environments, and integration with machine learning models for events type identification and predictive maintenance. Further research into reducing system costs and improving data transmission efficiency will also enhance the deployment of this technology at scale. Both controlled laboratory experiments and field trials under various environmental conditions are essential to validate performance and refine detection capabilities.

DFOS technology offers a comprehensive, real-time solution for monitoring entanglement and other hazards on FOSW infrastructure, significantly enhancing operational safety and maintenance strategies.

Question #2: What types of structural integrity or environmental monitoring technologies would be practical and cost effective to couple with detecting entanglement? What research is needed to advance these technologies? For example, continuous condition monitoring of electrical array cables, export cables, or mooring line integrity. Please provide as much detail as possible on the accuracy and cost of each technology and specify which parameters or conditions can be detected/monitored.

Distributed Fiber Optic Sensing (DFOS) offers a unique dual-function capability, providing both structural health and environmental impact monitoring for FOSW systems. Unlike conventional point-based sensors like strain gauges and hydrophones, DFOS continuously monitors entire lengths of structures, such as mooring lines and cables, with high spatial resolution down to millimeters. This technology detects strain, vibration, temperature, and acoustic signals in real-time, enabling it to identify structural issues like tension changes, bending, and corrosion, as well as environmental impacts, including entanglement, collisions, and other stressors. DFOS systems offer comprehensive coverage and multi-parameter monitoring that surpasses traditional sensors, making them cost-effective for large-scale applications. Research should focus on enhancing fiber durability, refining data analysis algorithms, and integrating AI for advanced event detection. DFOS's ability to simultaneously monitor structural integrity and environmental conditions positions it as a versatile, cost-effective solution for offshore wind infrastructure.

Question #5: To what extent are permanent FOSW infrastructure-mounted sensors more cost effective than deploying specialized vessels or equipment such as ROVs and AUVs? Please take into consideration the differences in sensor accuracy and the travel time of vessels from port to the FOSW farm.

Permanent sensors mounted on Floating Offshore Wind (FOSW) infrastructure, such as Distributed Fiber Optic Sensing (DFOS) systems, offer significant cost advantages over deploying specialized vessels, ROVs (Remotely Operated Vehicles), and AUVs (Autonomous Underwater Vehicles). These permanently installed sensors provide continuous, real-time monitoring of structural health and environmental conditions, eliminating the need for frequent, costly inspections that rely on vessel mobilization.

Cost Effectiveness: Deploying vessels, ROVs, and AUVs involves substantial operational costs, including mobilization, fuel, crew expenses, and downtime during transit from port to the FOSW site. Each deployment can cost tens to hundreds of thousands of dollars, with additional costs accumulating if frequent inspections are required. In contrast, infrastructure-mounted sensors have a one-time installation cost (typically $20,000 to $200,000 for DFOS), but they operate continuously without additional deployment costs, providing substantial long-term savings.

Sensor Accuracy: Permanent sensors, such as DFOS, offer high spatial resolution down to millimeters and can detect subtle changes in strain, vibration, and temperature, providing more detailed and accurate data compared to periodic ROV or AUV inspections, which rely on visual assessments and point measurements. This continuous monitoring allows for early detection of issues, reducing the need for emergency interventions that require costly vessel mobilization.

Travel Time and Accessibility: Travel time from port to the FOSW farm can add significant delays to inspection schedules, especially in adverse weather conditions, leading to further operational downtime and increased costs. Permanent sensors eliminate these delays by providing immediate data access, improving response times for maintenance and enhancing overall asset management.

Question #7: What are the biggest challenges in integrating permanently mounted sensors for structural integrity monitoring or environmental monitoring onto FOSW infrastructure? Please describe any current limitations with regards to sensor placement on platforms, mooring lines, electrical cables, or anchors.

Integrating permanently mounted sensors for structural and environmental monitoring onto Floating Offshore Wind (FOSW) infrastructure presents several challenges, including sensor placement, durability, power supply, data transmission, and maintenance in harsh marine environments.

Sensor Placement Challenges:

- **Platforms:** Placing sensors on FOSW platforms must account for complex structural geometries and exposure to extreme environmental conditions, such as high waves, strong currents, and corrosive saltwater. Ensuring sensors are placed in critical monitoring locations without interfering with structural components or turbine operations is a key challenge.
- **Mooring Lines and Anchors:** Sensors on mooring lines and anchors face severe mechanical stresses due to constant movement, tension fluctuations, and biofouling accumulation, which can degrade sensor performance and data quality. Mooring lines are also prone to entanglement, complicating the integration and maintenance of sensors.
- **Electrical Cables:** Integrating sensors onto electrical cables involves protecting them from electromagnetic interference and mechanical damage during cable deployment and operation. The movement and flexing of cables due to wave and current action can further stress the sensors, leading to potential data inaccuracies or failures.

Current Limitations:

- **Durability and Maintenance:** Permanently mounted sensors must withstand prolonged exposure to marine conditions, including biofouling, corrosion, and extreme weather, which can impair sensor accuracy and lifespan. The maintenance of these sensors is challenging and costly, as it often requires specialized equipment or vessels for inspection and repairs.
- **Power Supply and Data Transmission:** Providing reliable power to sensors in remote offshore locations and ensuring uninterrupted data transmission to shore-based monitoring systems are significant challenges. Wireless data transmission can be affected by environmental factors, while cable-based solutions add complexity and cost to the sensor setup.
- **Installation Complexity:** Installing sensors on critical areas like mooring lines, electrical cables, and anchors requires precise placement during deployment. Retrofitting sensors on existing infrastructure can be even more complex and may require downtime, impacting the overall operation of the wind farm.

Research Needs: Advancing sensor technology to improve resilience to biofouling, corrosion, and mechanical stresses is critical. Development of low-power, self-sustaining sensors with enhanced data transmission capabilities and robust protective coatings would significantly reduce maintenance needs. Additionally, innovative installation techniques and sensor designs tailored for specific FOSW components could enhance integration efficiency and performance, ensuring reliable monitoring across all structural elements.

Berkeley Lab appreciates the opportunity to provide these comments in response to the Request for Information regarding Entangled Debris Monitoring for Floating Offshore Wind Infrastructure.

The following individual contributed comments: Yuxin Wu.

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