April 2014

Events

Wave Energy Converter Extreme Event Modeling Workshop to be held May 13th-14th

A technical workshop will be hosted May 13-14th in Albuquerque, NM by Sandia National Laboratories and the National Renewable Energy Laboratory to discuss the modeling of wave energy converters in extreme conditions. Roughly 30 experts from research institutions and private companies have been invited to attend. Workshop discussions will focus on reviewing current modeling methodologies (both numerical and physical) and identification of areas best suited for future research.
Ryan Coe, (505) 845-9064.

Save the Date: 2014 Sandia Wind Turbine Blade Workshop August 25th-29th

The 2014 Sandia Wind Turbine Blade Workshop will be held at the Marriot Pyramid North in Albuquerque, New Mexico. The workshop provides a unique, blade focused collaborative forum that will bring together wind energy leaders from industry, academia and government. Stay tuned for updates. Information regarding past Wind Workshops can be found here.
D. Todd Griffith, (505) 845-2056.

GMREC/METS 2014 in Seattle, WA

Several members of the Sandia National Laboratories' Water Power Technologies department traveled to sunny Seattle, WA from April 14–17, 2014, to attend the Global Marine Renewable Energy Conference (GMREC) and the Marine Energy Technology Symposium (METS). These events, provide a forum for the MHK research community to publish and present their work in order to advance the industry, and creates a favorable environment in which to establish research partnerships. Daniel Laird, Vince Neary, Kelley Ruehl and Ryan Coe from the SNL Water Power department attended the conference and participated in the symposium.

Daniel Laird chaired a session on Resource Assessment and Characterization. Vince Neary chaired a session on MECs and the Environment: Assessing Environmental Impacts II, and presented several publications including his own, *Methodology for Design and Economic Analysis of Marine Energy Conversion (MEC) Technologies*, *CACTUS Open Source Code for Hydrokinetic Turbine Design and Analysis: Model Performance Evaluation and Public Dissemination as Open Source Design Tool,* by Carlos Michelen, *Field Measurement Test Plan to Determine Effects of Hydrokinetic Turbine Deployment on Canal Test Site in Yakima, WA,* by Budi Gunawan, and *Initial Characterization of the Wave Resource at Several High Energy U.S. Sites,* by Ann Dallman. Ryan Coe presented his own publication, *Review of Methods for*

Modeling Wave Energy Converter Survival in Extreme Sea States and *Model Validation using Experimental Measurements from the Garfield Thomas Water Tunnel at the Applied Research Laboratory at Penn State University*, by Budi Gunawan. On behalf of Diana Bull, Chris Smith from Penn State presented on the Pneumatic Performance of a Non-Axisymmetric Floating Oscillating Water Column Wave Energy Conversion Device in Random Waves. On behalf of Jesse Roberts, Kelley Ruehl presented *A Framework for Optimizing the Placement of Current Energy Converters*. Sandia's joint research projects and publications were also presented by SNL's collaborators. Yi-Hsiang Yu from NREL presented the joint SNL publication on WEC-Sim, *Development and Demonstration of the WEC-Sim Wave Energy Converter Simulation Tool*, Aaron Porter from Coast and Harbor Engineering presented the joint SNL publication on SNL-SWAN, *Further Development of SNL-SWAN, a Validated Wave Energy Converter Array Modeling Tool*, and Chris Smith from Penn State presented *Optimization and Annual Average Power Predictions of a BBDB Oscillating Water Column Device using the Wells Turbine.*

Both GMREC and METS had very good attendance from the MHK community. Attendees included the US DOE, MHK developers, regulatory agencies, utilities, stakeholders, and national and international research institutions such as labs and universities. The gathering provides the MHK community an opportunity to establish new partnerships and socialize new projects and research programs.
Daniel Laird, (505) 844-6188.
Vincent Neary, (505) 284-2199.
Kelley Ruehl, (505) 284-8724.
Ryan Coe, (505) 845-9064.

Wind Energy

Wind Plant Optimization

Wake-Imaging System Progresses to Outdoor Scaled Test

The wind turbine wake-imaging system being developed at Sandia, a novel system capable of measuring the velocity of three-dimensional coherent wake structures (e.g. tip vortices) over relevant time scales, will be deployed at an outdoor scaled facility as a final risk reduction experiment. The data collected with this system will be used to improve the physical understanding and modeling of wind turbine wake impacts on the power production and loads of down-wind turbines in a wind plant. The system will utilize a technique called Doppler Global Velocimetry (DGV) or Planar Doppler Velocimetry (PDV) on a larger dimensional scale and at lower velocities than previously demonstrated in other applications, which presents a variety of technical challenges. A typical DGV system includes a narrow linewidth laser, a frequency-to-intensity discriminator (iodine cell), and special digital cameras used collectively to measure the Doppler shift of scattered light from tracer particles within the flow field of interest. Currently in this project, Doppler measurements have been performed on a well-characterized target (spinning wheel) in a laboratory environment. The objective for the next stage of the project is to transition the system outdoors to determine how the method scales to larger viewing areas and to begin incorporating particle seeding to enhance the signal, two key issues that cannot be determined in a laboratory.

Figure 1 shows a schematic of the outdoor experiment. The test will consist of measuring the flow velocity from a 3 foot diameter fan within a 2m by 2m square viewing area. The flow into the fan will be seeded with particles 1 – 2 μm in diameter in order to enhance the signal. The structure (i.e. Sprung) will contain the fan and laser transmission optics to minimize the impacts of uncontrolled winds and to isolate the laser light for safety. The receiving optics (signal camera with iodine cell and reference camera) will be located in a van 33 m away from the fan to replicate the distances needed for eventual turbine testing. The DGV velocity measurements will be compared with mean velocity and turbulence statics obtained from other measurement instruments. Parameters such as the fan speed and the seeding concentration will be varied to determine the capabilities of the DGV system, including the signal-to-noise ratio and measurement uncertainty, that are needed as inputs to the design and deployment of the final system at the Scaled Wind Farm Technology Facility (SWiFT) site where the wake from research turbines will be investigated.

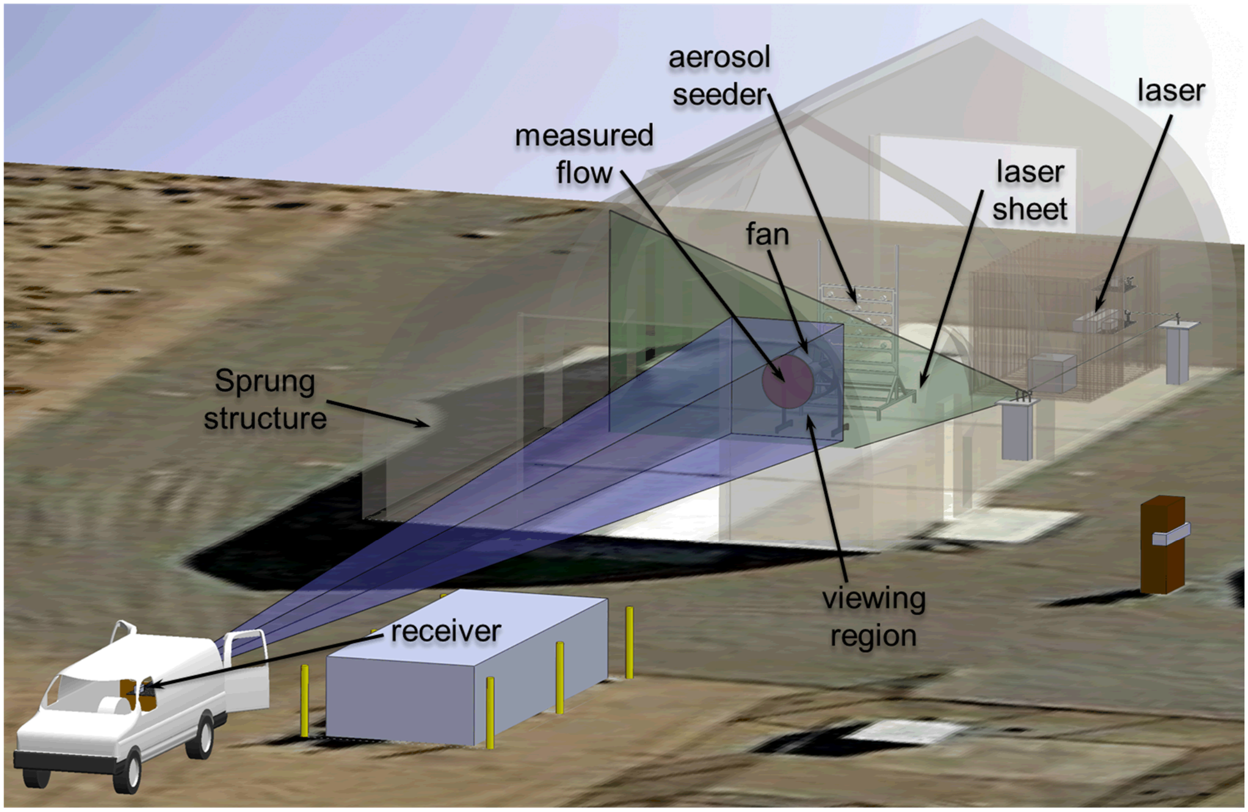


Figure 1 Schematic of the scaling experiment for the wake imaging system.

Tommy Herges, (505) 284-9760.

SWiFT Baselining Begins Streaming Data to Sandia

For the first time, research quality data from SWiFT has been transmitted to Sandia via automated protocols. This crucial step will allow for rigorous data analysis to be performed at Sandia, and later, to be transmitted to the public where industry, academia and national laboratories can improve wind plant simulations. The milestone was completed by the SWiFT Baselining Project team, who has been diligently working to verify that all instrumentation and data transmission capabilities of SWiFT will be ready for future research by the end of FY14.

Additional recent successes include completion and verification of the absolute yaw encoder, including the functionality for a live calibration to be performed later. The SWiFT meteorological data has also been analyzed on the currently installed atmospheric sensors, which include those sensors required for an IEC power performance test. The results from the analysis verified performance of the sensors and highlighted offsets and potential data quality issues to watch for as more data is collected. Work is progressing to improve the data quality by swapping out data acquisition hardware used with the sensors. This new system will be installed in May and rapidly verified to enable more accurate power

performance measurement starting by June 1st. Lastly, a signal naming convention and coordinate systems for all of the data collected at SWiFT has been finalized.
Jonathan White, (505) 284-5400.

SWiFT Operations Staff Back to 100 Percent

Norman Griffin and Miguel Hernandez have recently joined Texas Tech University, principally to support the daily operations of the SWiFT Facility. Both have received formal wind turbine technician training and Norman has worked over seven years in the industry performing major component change-out and a variety of other operations and maintenance activities. They join and complement a professional team of wind turbine engineers and technicians that will ensure the safety and productivity of the SWiFT Facility.

Recent accomplishments from SWiFT include the installation of the pitching shaft and reassembly of the pitching system on DOE / SNL #1 turbine during the week of April 21st, shown in Figure 2. Testing of the repair will be performed in the next weeks and if successful, the reinstallation of the rotor will occur mid-May. The goal is to have all three machines operational before the baseline turbine-to-turbine interaction data campaign is initiated in June. In the meantime, the Vestas and DOE / SNL #2 turbines have continued to run in supervised operation and have acquired more hours of operations in high winds.
Jonathan White, (505) 284-5400.

Figure 2 Installation of pitching shaft in DOE / SNL #1.

Rotor Innovation

Low load rotor design

A shift in rotor design philosophy has been underway for quite some time, but only recently has it been documented publicly. A nice example was seen at the European Wind Energy Association conference in Barcelona this year [1]. Remember the basic wind energy capture equation, $P = \frac{1}{2}\rho C_p A U_\infty{}^3$, where P is energy capture at the rotor, ρ is the density of air, C_p is the rotor power coefficient, A is the rotor swept area and U_∞ is the wind turbine inflow speed. The old design philosophy was to design highly efficient rotors, i.e. maximize C_p. However, commercially available turbines nowadays commonly exhibit C_p values of 0.48 or 0.50, with the practical maximum C_p when including drag and tip losses is around 0.52; there is not a lot of room to gain additional energy capture through increases in rotor C_p. Instead, the most straightforward way to capture more energy is through the increase in rotor size, $A = \pi R^2$. However, loads on the turbine (drivetrain, tower, etc.) from the rotor go up if C_p remains unchanged as rotors grow in size in order to capture more energy. Thus, the current trend in large rotors has actually been toward designs with low load at the cost of slightly lower C_p. Chaviaropoulos [1] describes an even more extreme case of a low load rotor where the induction distribution has been tailored to an optimal point with a significantly larger rotor swept area, reduced C_p, and no increase in rotor loads. This example demonstrates a shift in the rotor design paradigm and represents a future path for large rotors; they will be designed not purely from an aerodynamic perspective, but from a systems perspective that considers aerodynamics, structures, and full system loads. The approach leads to new challenges. For example, thick airfoils could be designed for high lift-to-drag performance at low (instead of high) lift coefficients. The implications of this new approach are not yet fully understood. For example, the rotor solidity is intentionally high for a low lift rotor, and the blades are thick for structural effectiveness. However, storm loads on high solidity rotors are high; low solidity rotors are preferred in stormy situations where the rotor is parked. Future work will no doubt help to assess the costs and benefits of the new approaches for rotor design. Design studies including these effects are in progress at Sandia. Low load rotors and their effects on turbine wakes in the wind farm array will be just one subject among many for future field test campaigns.

Comments by Brian Resor, (505) 284-9879.

1. Chaviaropoulos, P. K., and Sieros, G. "Design of Low Induction Rotors for Use in Large Offshore Wind Farms," *Proceedings of the 2014 European Wind Energy Association Conference*. Barcelona, Spain, 2014.

Materials, Reliability, & Standards

Materials, Reliability, and Standards

Sandia has recently completed the production of the final set of inspection panels to be used to evaluate non-destructive inspection tools as part of the Blade reliability collaborative. This is the final step in a multi-year task to investigate wind blade inspection methods, which started with open panels where manufacturers knew the locations and types of flaws, and were able to assess and improve their equipment. In contrast, this set of panels contain flaws that will not be known by the inspection technicians, and thus will allow for the technology to be evaluated in terms of its probability of detection (POD). Different types and sizes of flaws were embedded into sub-structure components representing critical structures in wind blades. The test specimens represent the most common structural designs seen on modern blades and underwent a thorough review by industry participants in the design phase. Sandia is actively seeking participants from NDI technology vendors, blade service companies, and blade manufacturers in this study.

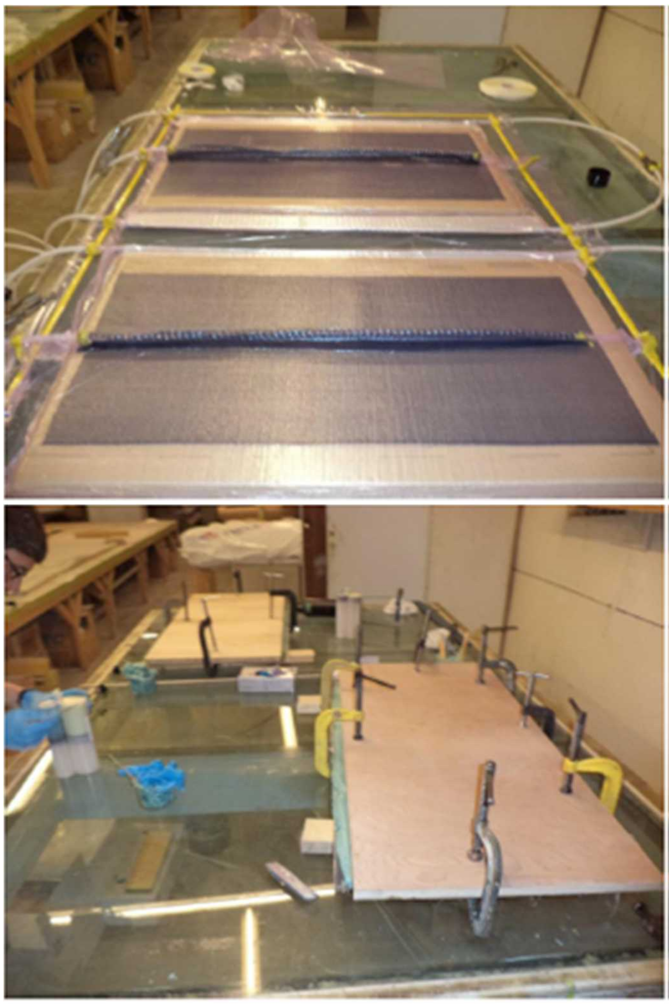


Figure 3 Wind Blade Non-Destructive Inspection Evaluation Panels in Production

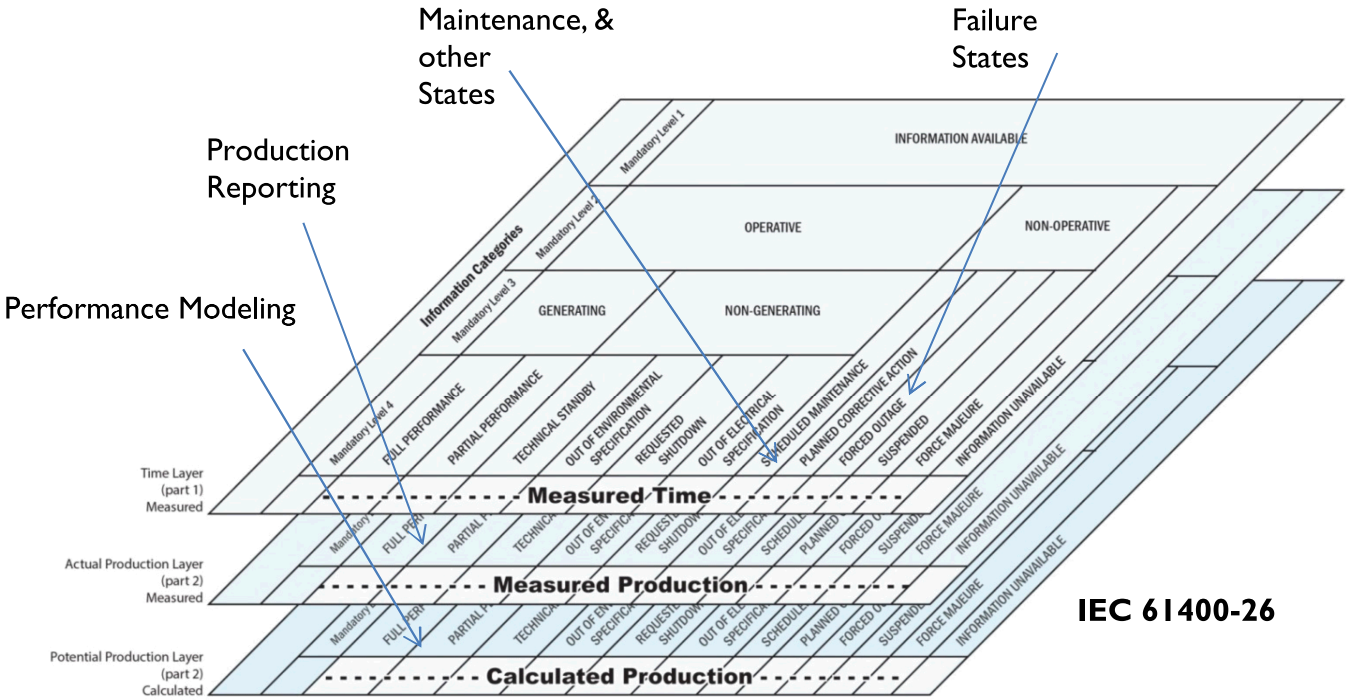
Additionally, as part of continued testing for the DOE/SNL/MSU Composite materials database, the first four-point beam test was completed on the newly built sub-scale test frame. This new piece of test equipment was specifically built to allow researchers to test wind turbine blade structures at an intermediate scale, examining how they perform under complex loadings and with embedded flaws. This will allow for better knowledge of how wind blade materials perform during turbine operation.

Finally, Sandia staff member Ben Karlson has been named project leader for the Continuous Reliability Enhancement for Wind (CREW). The CREW project seeks to acquire reliability data from the nation's wind turbine fleet and turn that data into actionable intelligence to inform targeted research projects focused on the most important reliability problems. The next phase of CREW will be to work with wind farm owners and operators to target reliability data that is not collected by the turbine control system.

IEC 61400-26 Availability Standard

The U.S. Department of Energy Wind Program and Sandia National Laboratories have been working with the International Electrotechnical Commission (IEC) Committee on Wind Turbine Availability to develop three specifications for IEC-61400-26—the standard that addresses wind turbine and wind plant availability. The first specification is on the definitions of operating states and availability conditions and was published in 2011. The second specification is on time-based energy production and it defines a methodology for production accounting for differing operational states of a wind turbine, considering internal and external conditions. For example, it defines accounting for potential production, actual production, and lost production with determination and example verification scenarios. The second specification has been completed and approved and will soon be published. The third specification in this series is for production for a full wind power station, including the balance of plant components of energy collection systems, substation and interconnection, and provisions for the human (functional) element of operations and maintenance. Based on the Sandia Continuous Reliability Enhancements for Wind (CREW) team's observations and experience, common mode failures will affect multiple elements of both the balance of plant and the turbines of the wind power station. Although the balance of plant does not generate power, its failures adversely affect both time and production-based availability. These failures impact the balance of plant's role in electricity transmission and the turbines' dependency on the non-turbine components.

This work will lead to standardized and mandatory reporting metrics for full wind plants when the technical specifications are invoked as a standard and/or requirement. These standards help to define requirements to support clear understanding of contract terms for performance of turbines and wind plants. This is achieved by providing an information model specifying how time designations shall be split into information categories. The accompanying illustration and table identifies the information model accounting for time, as well as measured and calculated energy.



Information Model for IEC Technical Specification 61400-26-2: Production-Based Availability for Wind Turbines

Condition State	Example
Full performance	Function with no limits or restrictions
Partial performance	Functioning with limitations and/or restrictions
Technical standby	Temporarily nonfunctioning due to controlled and/or predefined tasks required - e.g. self-testing, ramp-up
Out of environment spec	Operative but not functioning as the environment is out of design specs
Requested shutdown	Operative but stopped by an external request-i.e. curtailment

Out of electrical spec	Operative but not functioning as the electrical parameters are out of design specs - i.e. grid outage
Scheduled maintenance	Scheduled maintenance prevents system components for performing the intended functions
Planned corrective action	Actions required to retain, restore, or improve the intended functions that are not part of normal scheduled maintenance
Forced outage	Action taken as unforeseen damage, faults, failures or alarms are detected
Suspended	Activities in SCHEDULED MAINTENANCE, PLANNED CORRECTIVE ACTION and FORCED OUTAGE are interrupted or cannot be initiated due personal safety or equipment integrity - e.g. extreme weather
Force Majeure	Extraordinary event or circumstance beyond the control of the parties, prevents the parties from fulfilling their obligations.

IEC 61400-26 identifies a common basis for information exchange on performance indicators between owners, utilities, lenders, operators, manufacturers, consultants, regulatory bodies, certification bodies, insurance companies and other stakeholders in the wind power business. It is used to help define requirements to support clear understanding of contract terms.

Table 1 States of availability

Meeting held in Brande, Denmark

Roger Hill of Sandia National Laboratories traveled to Brande, Denmark to attend the International Electrotechnical Commission 61400-26 committee meeting on wind turbine availability standards on April 7-9. The meeting was hosted by Siemens Wind Power and also attended by industry leaders such as Vestas, Nordex, Bachman, RWE Energy, DONG Energy and GL Garrad Hassan. Bob Sherwin of Vermont Wind Power chaired the meeting. At this meeting, a model was further developed to incorporate the progress of the first two technical specifications of this work, for time based and production based availability, and incorporate the complex notion that for the balance of plant, which does not generate but whose failures adversely affect time and production based availability, that common mode failures will affect multiple elements of both the balance of plant as well as the turbines of the wind power station. Roger Hill took an action item to develop illustrations that will demonstrate the balance of plant role in transmission of energy and the turbines dependency on it, as well as failures at various points becoming common mode failures.

The information model will apply to the wind power station as a whole, and the external impacts apply to some of the condition different states. As a practical matter, it will also be important to differentiate between the turbines and the BOP, since turbine supply contracts have stated financial factors applied to the turbine performance separate from that of the whole plant. Only the turbines generate power, but the BOP will have parasitic losses and even loads when the turbines are non-operational.

Roger provided a simplified one line diagram of a representative wind plant and compared and contrasted that to a reliability block diagram of the same overall design. It is important to realize that, while some levels of redundancy can be built into the infrastructure of the plant, the turbines operate in a module fashion. The next meeting is scheduled to be held in Hamburg on June 2-4.

The part 3 technical specification information model will form the basis for how to allocate time for reporting availability and reliability indicators that include balance of plant systems and components. Acceptance of mandatory reporting requirements will likely happen as the specification is upgraded to a standard (expected after publication of part 3) and is invoked as a requirement. As this happens, it will institutionalize appropriate and needed data collection and reporting for buyers and sellers in the market. These interactions facilitate an international and industry dialog and exchange of information related to wind energy reliability.
Roger Hill, (505) 844-6111.

Offshore Wind

Siting & Barrier Mitigation

Wind Generator Modeling

Sandia finalized and submitted the updated “WECC Wind Power Plant Dynamic Modeling Guide” and the “WECC PV Power Plant Dynamic Modeling Guide” to the Technical Studies Subcommittee at the Western Electricity Coordinating Council (WECC). These dynamic modeling guides present the second generation generic models as specified in the January 23, 2014 WECC report[1]. The WECC generic models were designed for large transmission planning studies that involve a large network, and a large set of generators, loads and other dynamic components. The objective is to assess dynamic performance of the system, particularly recovery dynamics, following grid-side disturbances such as transmission-level faults. The development of the second generation of generic models is the result of large industry collaboration.

Ben Karlson , (505) 844-9844.

Tool for Siting Planning and Encroachment Analysis for Renewables

The Department of Energy and Sandia National Laboratories continue to work toward understanding the effects of wind turbines on the environment where they are placed in order to identify and mitigate the barriers to develop wind energy systems. As part of this effort, wind turbine/ radar interference models have been produced as part of the Tool for Siting Planning and Encroachment Analysis for Renewables (TSPEAR). The TSPEAR toolkit supports energy development interests, including developers, consultants, and government agencies, who wish to design, analyze, track progress, and maintain configuration control of energy projects. Initially, the toolkit was designed to support wind energy developments and assess the impact on potential constraining factors, namely National Air Space (NAS) Radar systems. The TSPEAR framework provides connections to databases which already exist and are maintained by third parties, while also providing the capability to add custom models and tools.

The current version of TSPEAR includes a portal capability to combine a commercial planning/ management tool with an existing radar model of the Common Air Route Surveillance Radars (CARSR) within the Contiguous US, a line-of-sight analysis tool, and the ability to create radar "Viewshed" for all NAS radar systems, including all Air Route Surveillance Radars (ARSR), Airport Surveillance Radars (ASR). A sample Viewshed is shown in Figure 4.

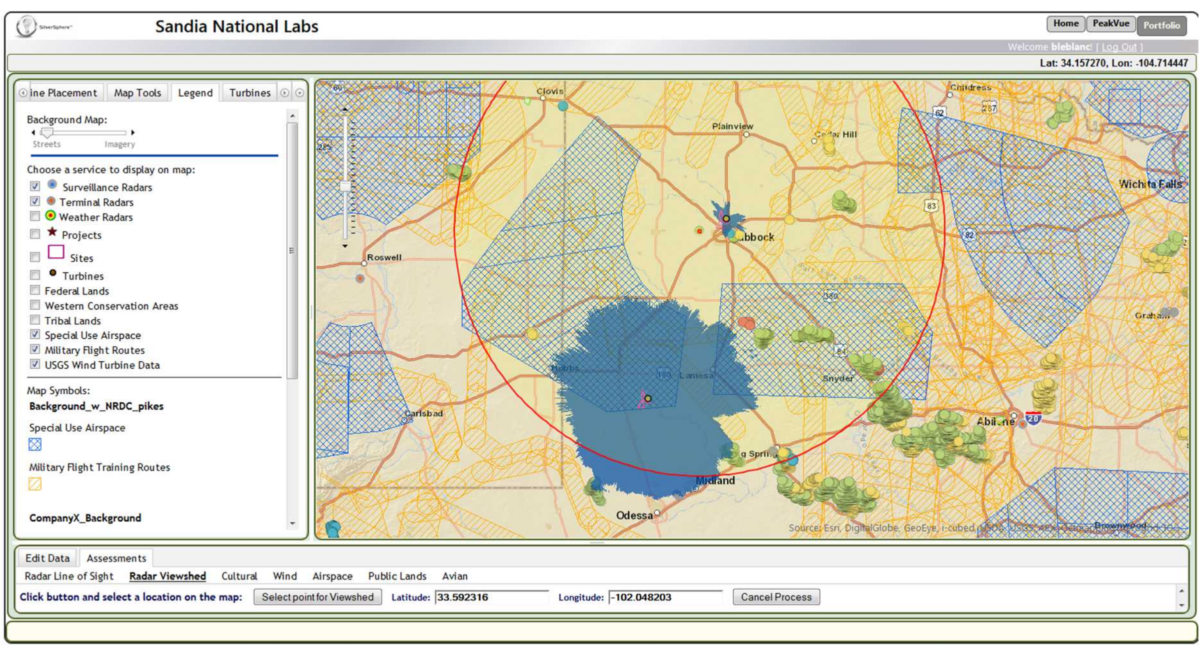


Figure 4 Radar Viewshed at a height of 500 feet AGL displaying radar coverage, Military Operating Areas, and currently installed turbines.

A contract was placed with BEM intl. LLC. to begin the Phase II development of TSPEAR. This phase will expand the detailed radar model to include the remaining ARSR and ASR radars in the Continental US. A detailed study of turbine RCS and its sensitivity on the detailed model results will also be examined. Many efforts have been made to showcase the tool for the Department of Defense, Office of the Secretary of Defense siting clearing-house, the Department of Energy and the FAA for inclusion of the TSPEAR framework in the process of project approvals.
Bruce LeBlanc, (505) 844-1438.

Wave Energy

Resource Assessment

Ocean Sciences, UH & Sea Engineering Meetings

Ann Dallman traveled to Honolulu, HI in February to deliver a presentation on Sandia's wave resource characterization activities at the AGU Ocean Sciences Meeting in the 'Marine Renewable Energy Research, Development, Evaluation, and Policy' session. This was the first year of this particular session, and the session received a lot of interest from the meeting attendees. Sandia's wave resource project involves compiling detailed resource assessments at three high energy U.S. test sites to provide an open-source 'catalogue' for industry. Hindcast simulation and measured buoy data will be used to calculate resource statistics as well as estimates of weather windows and extreme events. The three sites included in this project are (1) the Wave Energy Test Site (WETS) in Kaneohe Bay, (2) the North Energy Test Site (NETS) at the Pacific Marine Energy Center, offshore of Newport, OR, and (3) a potential test or development site offshore of Humboldt Bay, CA.

Ann also met with researchers at the University of Hawaii regarding their research and hindcast modeling of the wave resource around Oahu, in particular at the Wave Energy Test Site (WETS) in Kaneohe Bay. Members of the Sea Engineering staff at the university conducted a site visit of the WETS facility, which is shown in Figures 5 and 6, below.

Figure 5 Top view of the Wave Energy Test Site (WETS) in Kaneohe Bay, HI. Source: http://azurawave.com/projects/hawaii/

Figure 6 Outlook from the onshore connection point of the Wave Energy Test Site (WETS) in Kaneohe Bay, HI. The test site is located directly ahead.

Ann Dallman, (505) 844-8675.

Device Modeling

Modeling the Power Pod

Planning an open water test facility for utility-scale WECs within the United States requires a multifaceted approach. Concerns regarding the siting and permitting, the environmental interactions, the device performance, and the cost of the facility must all be simultaneously addressed. The DOE has started to investigate a utility-scale WEC testing facility with the recent awards to Oregon State University (OSU) and California State University San Luis Obispo to evaluate launching a facility off of either the Oregon or California coast.

These test sites are intended to be WEC type agnostic, meaning that they should be suitable for deployment of a variety of device embodiments. Additionally, these sites are intended to have multiple berths open to developers, thus allowing multiple devices to be tested simultaneously. The method for transmitting power from multiple devices back to shore normally involves a central power pod that conditions the power prior to transmission to shore.

As part of this effort, SNL will work with OSU to look at the requirements for a facility provided power pod. This work will evaluate the power characteristics of multiple device embodiments. The set of power characteristics will be used to model the internal power electronics of the pod, thus assisting the project team in determining the applicability of a single set of electronics for the pod. Additional modeling to determine the dynamics of a floating pod will be used to assist the project team in evaluating the placement of the power pod within the water column.

Modeling of power characteristics through the power pod electronics allows deeper insight not only for the utility-scale test facilities, but is also an important step for understanding the requirements for large array deployments. These modeling efforts are anticipatory of the upcoming needs of the MHK industry and are expected to help frame the same conversation industry will conduct as it deploys its arrays.
Diana Bull, (505) 284-5607.

Array Performance & Environmental Effects

MHK Acoustics: Modeling Propagation

A large environmental and regulatory concern surrounding marine hydrokinetic (MHK) deployment of both current energy converters (CEC) and wave energy converters (WEC) is the sound spectra/levels produced from individual devices and arrays of devices and how that sound propagates through an environment to interact with marine life. As part of SNL acoustic studies, a white paper has been developed outlining modeling methods available for underwater acoustic propagation and their realms of applicability (shown in Table 1). The paper concludes with a recommendation on which method will provide developers and researchers a tractable tool to determine sound spectra and levels within a marine environment resulting from a MHK deployment.

Models	Shallow Water				Deep Water			
	Low Frequency		High Frequency		Low Frequency		High Frequency	
	1D	2/3D	1D	2/3D	1D	2/3D	1D	2/3D
Ray Theory			/	■	/	/	■	■
Normal Modes	■	/	■	/	■	/	/	
Parabolic	/	■			/	■	/	/
Elastodynamics	■	■	■	/	■	■	■	/

Table 1 Applicability of the three principal acoustic propagation methods in representative domains and linear elastodynamics, adapted from [1]. Filled cells are both computationally and physically applicable, hashed cells are practical but limited in scope.

Of the available models, ray theory, normal modes, and parabolic equations are the most widely used and each is derived from the three-dimensional wave equation, with simplifications to specific solution domains. Shallow water is classified as a depth of less than 200 m, the high- and low-frequency division is 500 Hz, and the spatial dimensions are depth, radial distance, and azimuthal angle from the source on the horizontal plane (1/2/3D, respectively). Of these, the parabolic equation models would be most appropriate for MHK sound propagation in terms of environment, frequency range, and computational efficiency. However, while these methods approximate spatial variation in three-dimensions, it is achieved through a collection of two-dimensional slices radiating from the source. For initial tidal and wave deployment sites this formulation will result in shadow regions and an under prediction of backscattered and reflected noise. An alternative method, and the one recommended for development, is based upon time-varying strain waves in elastic media. This method is potentially more computationally expensive based upon the frequencies investigated and domain size, but makes none of the assumptions used in the above models and solves a fully three-dimensional domain. A linear, finite-difference model has already been developed at SNL and validated for both geophysical/seismic studies and wind turbines and it is currently being adapted to support the marine renewable energy sector.

[1] P. C. Etter, "Advanced Applications for Underwater Acoustic Modeling," *Advances in Acoustics and Vibration,* vol. 2012, p. 28, 2012.

Jesse Roberts (SNL), 505-844-5730.
Erick Johnson (MSU), 406-994-6163.

SNL-SWAN Beta Code Development: Frequency Dependent WEC Module

SNL is developing accurate methods to simulate altered wave propagation due to the operation of wave farms by enhancing the open source spectral wave model SWAN. The new model, SNL-SWAN, remains open source and will help the WEC industry assess the potential environmental effects created by changes in wave climates associated with the deployment of various sizes and configurations of wave farms in the ocean.

Recently, SNL has modified the SNL-SWAN Alpha code to include a frequency dependent WEC Module. This latest version has been named SNL-SWAN Beta. The SWAN test cases were run to verify the baseline code's functionality. and the frequency dependent functionality of SNL-SWAN Beta's WEC Module was verified. This was accomplished by comparing the shape of the incident energy spectrum (before the WEC) to the lee energy spectra (after the WEC), and noting varying energy absorption in different frequency bins. Figure 6 shows the model applied to a hypothetical case. The red line shows the SNL-SWAN Alpha model (applies a constant absorption coefficient across the entire spectrum; the coefficient used is the value of the RCW curve (blue) corresponding to the incident frequency with the most energy). The green line shows the SNL-SWAN Beta model incorporating frequency dependence by applying a variable absorption coefficient to the different frequency bins of the simulation based on WEC power performance data from the RCW curve.

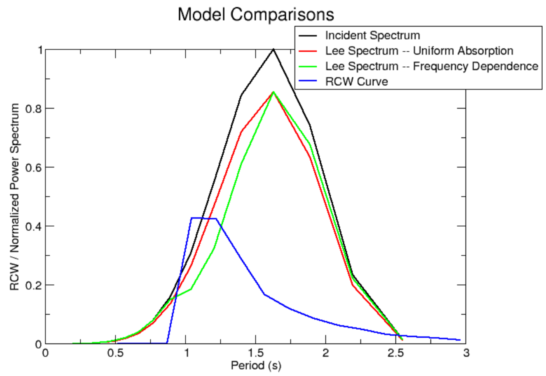


Figure 7 Conceptual comparison of spectral transformation using baseline (red), SNL-SWAN Alpha (blue) and SNL-SWAN (beta) green directly at LEE of WEC.

SNL-SWAN Beta was then used to model the Columbia Power array tests performed in the Oregon State Tsunami Wave Basin, as shown in Figure 7. The results of these simulations were then compared to the experimental data from these wave tank tests, and also to simulations using the baseline SWAN code, SNL-SWAN Alpha, and the OSU Module for SWAN, as shown in Figure 8 and F9. Baseline SWAN models the WEC as a constant transmission coefficient, SNL-SWAN Alpha calculates a constant effective power transmission coefficient based on the WEC's power performance data, and the OSU Module is a function external to SWAN that is used to modify the wave spectra at the line of WECs, and then re-propagate that spectra to the next line of WECS. Theoretically, the OSU Module and SNL-SWAN Beta version should be very similar because they are both frequency dependent. However, since the OSU Module is external to SWAN and requires multiple runs of SWAN, there may be numerical artifacts from the additional boundary conditions. This work was published in the GMREC/METS 2014 conference proceedings, and presented in Seattle on April 17, 2014.

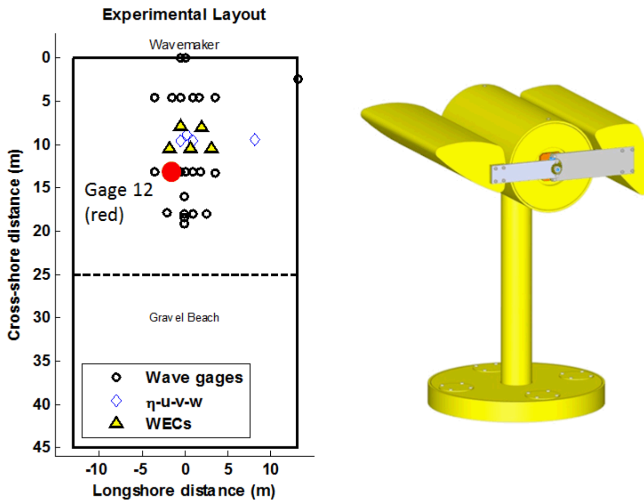


Figure 8 (LHS) The experimental layout with wave gages (circles) and WECs (triangles), ADCPs (diamonds). Yellow WECs indicate the setup for the 5-WEC arrangement. (RHS) A rendering of the ColPwr WEC MANTA 3.1.

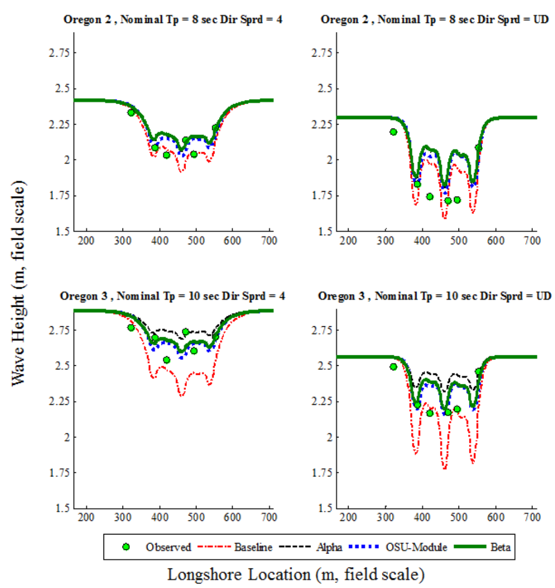


Figure 9 Wave height transects of observations and model iterations for two incident wave states (OR2 and OR3) at two different directional spreading parameters (S=4, and unidirectional).

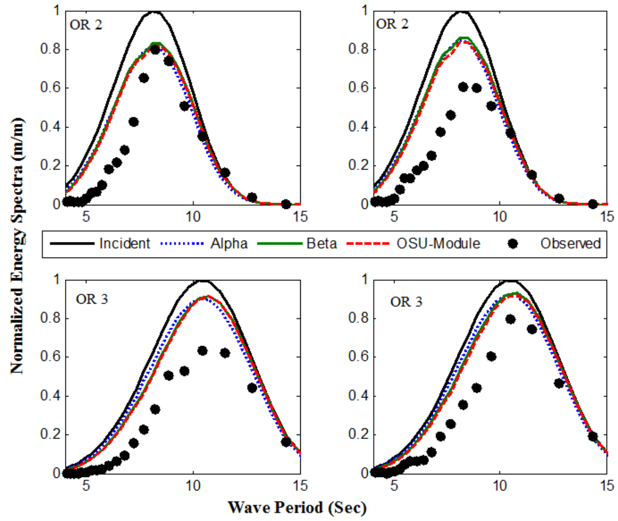


Figure 10 Energy spectra at gage in the lee of the WEC-Array for OR2 (top) and OR3 (bottom) and directional spreading on (LHS) and off (RHS).

Kelley Ruehl, (505) 284-8724.
Chris Chartrand, (505) 845-8750.

Advanced Materials & Manufacturing

Biofouling Studies on Sandia's MHK Coatings Initiated at PNNL's Sequim Bay

Sandia's Materials & Manufacturing Reliability Program has begun testing their novel MHK coatings at Pacific Northwest National Laboratories Sequim Bay facility. Tests will reveal anti-biofuling efficacy of coatings developed for MHK technology and of commercial coatings. Over 150 coupons (1x1, 3x3 and 8x8 in) will be examined in testing tanks using water from Sequim Bay. Below are images of some of the tanks that will be employed to measure attachment of bacteria, algae, barnacles and other species native to the bay's environment. PNNL's George Bonehyo is leading the testing.

Figure 11 MHK technology at PNNL Sequim Bay

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Reference Models

Promoting Open-Source Research to Advance MHK Technologies: The Reference Model Project (RMP) Site

The Reference Model Project (RMP), sponsored by the U.S. Department of Energy (DOE), is a partnered effort to develop marine hydrokinetic (MHK) point designs for wave energy converters and tidal, ocean, and river current energy converters and a methodology to design MHK technologies and evaluate their levelized cost of energy (LCOE). For those interested in finding out more details, supporting documentation for the RMP project is archived at http://energy.sandia.gov/rmp. In addition to the main report that details the project, supplementary documents, including supporting design and analysis reports, 3D CAD geometry files and Excel spreadsheet files which calculate detailed cost breakdown structures and LCOE, are available for download.

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Current Energy

Array Performance and Environmental Effects

Performance Testing for Hydrokinetic Canal Effects: Field Measurement Preparations

SNL is working with the U.S. Bureau of Reclamation (USBR) and Instream Energy Systems (IES) to determine the performance and impacts of a hydrokinetic turbine on water-operations in Roza Canal, Yakima, WA, through both field measurements and numerical modeling. SNL completed a test plan for characterizing inflow and wake flow fields and turbine performance. SNL and the other stakeholders will travel to the site in May 2014, for the first of several field measurement campaigns. As part of the test plan, SNL will deploy an acoustic Doppler current profiler (ADCP) and acoustic Doppler velocimeters (ADV) using a customized cableway system to obtain high resolution near wake velocity and turbulence measurements. USBR will measure the turbine inflow velocity using an ADCP, deployed using SNL's tethered boat. In addition, SNL will also use a remote controlled boat (shown in Figure 11) for conducting a bathymetry survey and obtaining velocity measurements over a larger area along the canal, for numerical model boundary conditions and validation. SNL purchased a set of strain gages and a wireless telemetry system for measuring the turbine torque and thrust. IES, designPORT inc and SNL will be working together to mount this system on the shaft of the turbine.

The project activities in April 2014 include:

- Presented a paper entitled *Field Measurement Test Plan to Determine Effects of Hydrokinetic Turbine Deployment on Canal Test Site in Yakima, WA*, during the 2014 Marine Energy Technology Symposium
- Built a customized cableway system to deploy ADCP and ADV systems along evenly spaced cross-sections of the channel
- Received training for the remote controlled survey boat operation, including boat trials in the San Diego Model Yacht Pond
- Tested SNL's ADCP at the St. Anthony Falls Laboratory (SAFL), University of Minnesota Main Channel Facility

The survey boat and the ADCP were tested successfully and, together with the other instruments, will be shipped to the site in early May 2014.

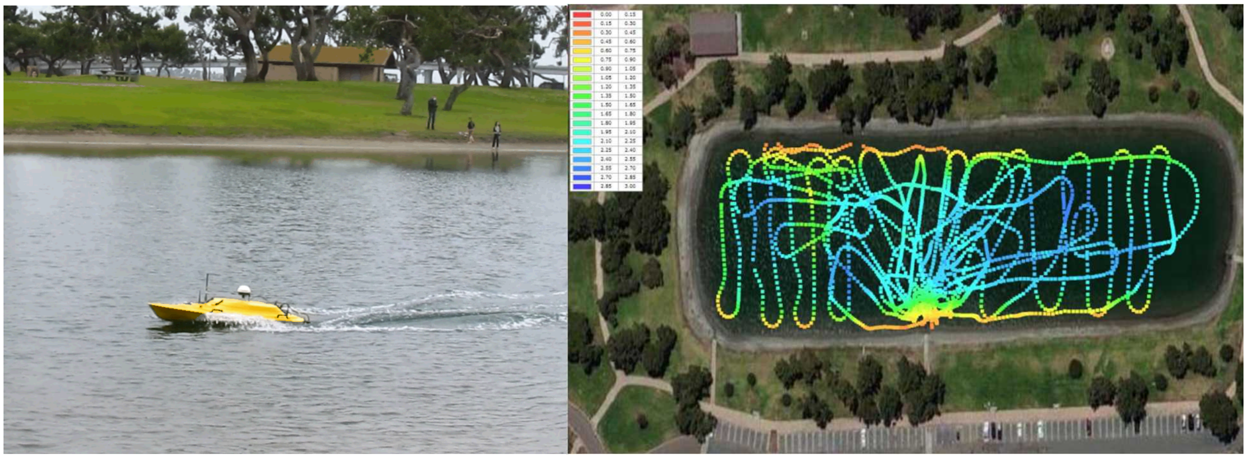

Figure 12 The survey boat testing in the San Diego's Model Yacht Pond (left) and the raw bathymetry measurement results (right). The results can be interpolated to predict the bathymetry at the unmeasured location.

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Recent Upgrades to SNL-EFDC: A Tool to Balance MHK Energy Generation Efficiency with Environmental Response

SNL-EFDC is an open source tool developed to support the marine renewable energy industry by enabling simultaneous evaluation of array power production and environmental effects, facilitating optimal device placement. SNL-EFDC is an augmented version of US EPA's Environmental Fluid Dynamics Code (EFDC) that has been well validated against real world river, lake, tidal, and other coastal environments. Sandia has included a new module within SNL-EFDC that simulates energy conversion by marine hydrokinetic (MHK) current energy converter (CEC) devices and evaluates commensurate changes in the turbulent kinetic energy and turbulent kinetic energy dissipation rate.

SNL-EFDC has recently been upgraded to be compliant with Visual EFDC (VEFDC),. Tetra Tech's graphical user interface (GUI), VEFDC was designed to develop and edit orthogonal grids needed by EFDC, edit all the input files required by the program, and visualize the output. VEFDC includes a Windows/GIS-based interface for creating necessary EFDC input files and displaying output results; it also includes a number of utility programs. Altogether, VEFDC was designed to replace the GEFDC (GridEFDC) and VOGG (Visual Orthogonal Grid Generator) tools as well as EFDC Version 1.1. Tetra Tech has preliminarily agreed to make VEFDC freely available to the MHK community if Sandia develops SNL-EFDC to work seamlessly with this GUI.

VEFDC expects a very specific format when reading the main EFDC input file, EFDC.INP. Moreover, VEFDC will read a set of binary output files generated during the course of an SNL-EFDC run. If VEFDC is to be used as the GUI for MHK simulations, then SNL-EFDC must be able to both read the file format of EFDC.INP written by VEFDC as well as to write binary output files readable by VEFDC. Both of these formats (input and output files) differ from those used by EFDC Explorer (EE), the formerly free GUI that was used by SNL-EFDC to develop MHK models and visualize the model results.

SNL-EFDC has been upgraded to determine whether it is reading the VEFDC or EE version of input files. This allows SNL-EFDC to be used for all legacy models built when EE was the GUI of choice while also being able to read VEFDC input files after transition to the new GUI. Tetra Tech is in the process of gathering the necessary files to specify VEFDC binary output. As soon as these are received, they will be incorporated directly into SNL-EFDC so that MHK simulations can be visualized with VEFDC. Existing output formats compatible with EE will be maintained so that legacy models can still be run and visualized with EE, while also ensuring that VEFDC is the GUI of choice when moving forward.

Finally, efforts to finalize the SNL-EFDC model verification journal article continue. It is important to verify that the recent code changes do not affect the model results; models used in the development of this manuscript are being baselined with the new SNL-EFDC executable. Chris Chartrand of Sandia has recently joined the SNL-EFDC development team. He is currently analyzing the source code in order to gain a full understanding of the model and the methods implemented, and will become a significant contributor to the upcoming code development.

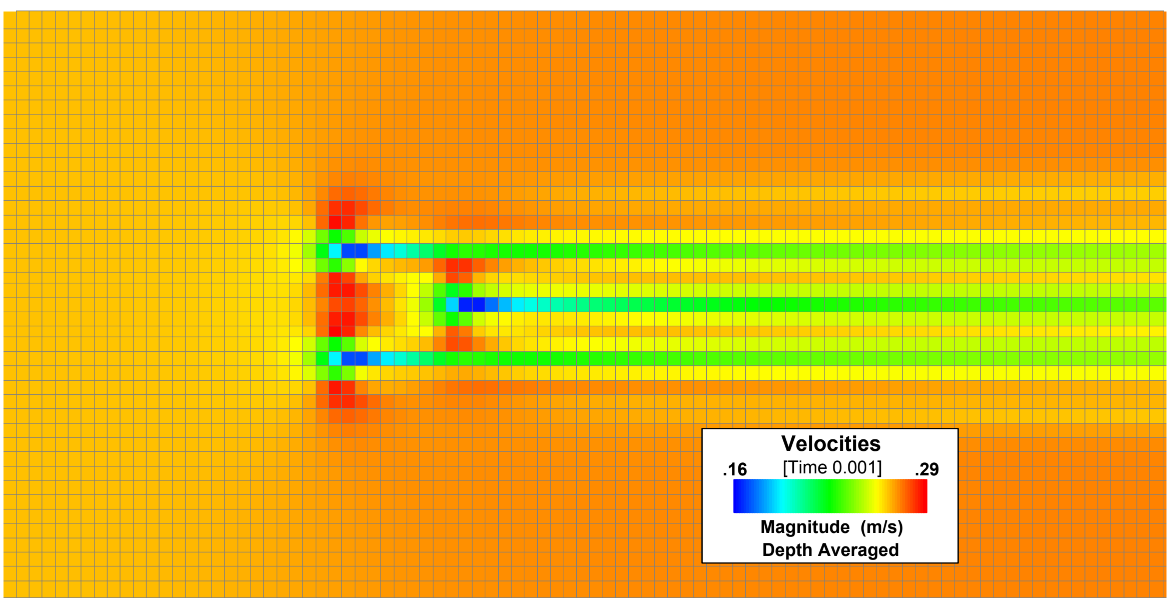

Figure 13 Top view of depth-averaged velocities of flow past a three-actuator-disk-array as simulated by SNL-EFDC. The model was compared with the data collected in the Chilworth flume at University of Southampton, UK.

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Advanced Materials & Manufacturing

Investigations on Structural Health Monitoring of MHK Turbine Foils Presented at GMREC METS

Sandia's Instrumentation and Materials & Manufacturing Reliability Program presented their initial work to explore structural health monitoring for MHK turbine foils at the 2014 Global Marine Renewable Energy Conference. This research was also accepted for publication in the Proceedings of the 2nd Marine Energy Technology Symposium. The research resulted from a CRADA between Ocean Renewable Power Company, Sandia and NREL. Micron Optics also participated by helping to guide sensor selection. Professors Erick Johnson and David Miller of Montana State University led the team in helping to characterize Fiber Bragg Grating Sensors on a sectioned turbine foil shown in Figure 13, below. The abstract of the paper is presented below.

Figure 2 – Section of an ORPC-supplied foil,from which coupon substrates were cut.

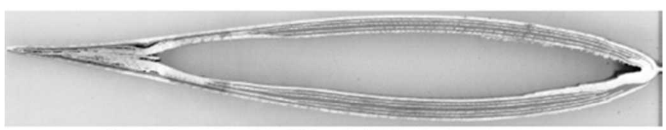

Figure 3 – Cross-section of the ORPC-supplied foil showing the laminate layup.

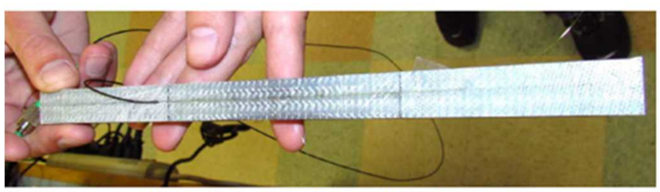

Figure 4 – Test specimen with a mounted MOI bare FBG sensor.

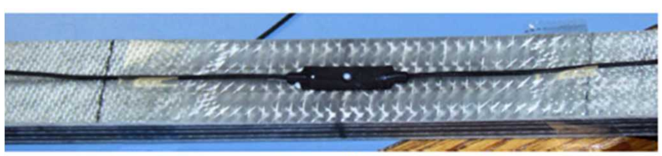

Figure 5 – Test specimen with a mounted MOI standard-package FBG sensor.

Figure 14 Fiber Bragg Grating Sensors on a sectioned turbine foil

EXTERNALLY BONDED FBG STRAIN SENSORS FOR STRUCTURAL HEALTH MONITORING OF MARINE HYDROKINETIC STRUCTURES

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Abstract:

To reduce operations and maintenance costs, mitigate failures, and improve capacity factor, structural health-monitoring systems can provide key information to improve management of marine hydrokinetic devices. While present systems include instrumentation to measure power output, few adequately monitor mechanical loads and structural response, which are equally important for determining device performance and integrity. Fiber optic Fiber Bragg Grating (FBG) sensors could prove to be a reliable and unobtrusive measurement tool for marine power; however, externally adhered FBGs have not been extensively studied on submerged, dynamic structures. Thus investigations on the bond integrity between sensor and structure of a kinetic system, FBG strain sensors were tested in dry and environmentally soaked conditions under both static and fatigue loads. Composite coupons were strained in a fatigue testing system and monitored. Dry results demonstrated very high correlation and response from the FBG sensors, up to coupon failure. The environmentally soaked samples and sensors were subject to many failure modes and verified the developer's recommendation to not externally adhere the FBG strain sensors without additional mechanical and environmental protections.
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Travel

- May 10-15, 2014- Yakima, WA
  Travelers: Guild Copeland & Budi Gunawan
  Purpose: Field measurements in Roza Canal

- May 19-21, 2014- Washington, DC
  Traveler: Brandon Ennis
  Purpose: 4th Defense Renewable Energy Summit

- June 8-13, 2014- San Francisco, CA
  Travelers: Kelley Ruehl, Carlos Michelen, Carsten Westergaard
  Purpose: Attend the 2014 OMAE Conference

- June 10-July 15, 2014- Delft, Netherlands
  Traveler: Todd Griffith
  Purpose: Participate with TU-Delft as a visiting researcher

- June 16-21, 2014- Copenhagen, Denmark
  Travelers: Todd Griffith, Brian Owens & Phillip Richards
  Purpose: To attend the Science of Making Torque from Wind Conference at DTU