Recent Developments in the WEC-Sim Open-Source Design Tool

Preprint

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1 Sandia National Laboratories
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Recent Developments in the WEC-Sim Open-Source Design Tool

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I. Keywords

Wave energy converter, hydrodynamics modeling, WEC-Sim, power take-off, mooring, and multibody dynamics

II. Abstract

WEC-Sim is an open-source code for simulating wave energy converters, which has been actively developed and applied to simulate a wide variety of device archetypes and has become a popular tool since its initial release in 2014 [1]. WEC-Sim is developed jointly by the National Renewable Energy Laboratory (NREL) and Sandia National Laboratories (SNL) within the MATLAB/SIMULINK environment. Figure 1 illustrates a general wave-to-wire model that begins with a deployment site resource characterization, which is used to complete the hydrodynamic simulation of a single wave energy converter (WEC) (or array), with the power generation profile imported to a grid simulator to understand the influence on the local electrical network. While modeling the entire wave-to-wire is difficult and encompasses multiple time scales and physics, WEC-Sim is focused on the hydrodynamics simulation to predict, analyze, and optimize WEC dynamics and power performance. WEC-Sim simulations are performed in the time domain based on the radiation and diffraction method [2] using hydrodynamics coefficients derived from boundary element method (BEM)-based frequency-domain potential flow solvers (e.g., WAMIT, NEMOH, Capytaine, or ANSYS-AQWA). Within this level of modeling fidelity, WEC-Sim can handle floating body hydrodynamics [3], mechanical and electrical power generation methods, advanced control implementation [4], mooring systems, and other unique applications such as desalination [5]. Table 1 lists additional WEC-Sim functionalities, which are created using prebuilt Simulink blocks and MATLAB scripts that can simulate a wide range of floating systems and the corresponding auxiliary subsystems.

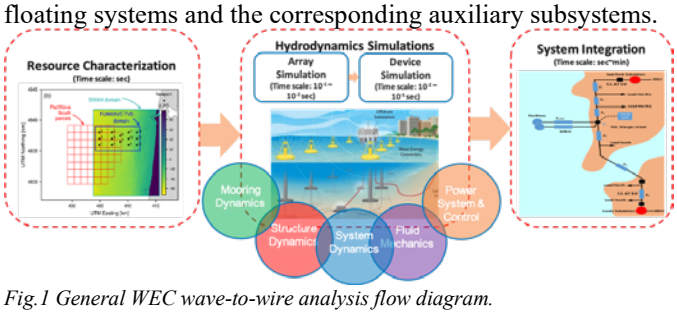

Fig.1 General WEC wave-to-wire analysis flow diagram.

Table 1. Prebuilt WEC-Sim blocks and functionalities.

Environment	Constraint/PTO	Body Dynamics	Mooring
Regular waves, Irregular waves	Rotational, Linear	Rigid body, Flexible body	Mooring matrix, MoorDyn
Other Functionalities			
Boundary element method functions		Morison elements	
Nonlinear hydrodynamics		Generalized body modes	
Mean drift force calculation		Run from Simulink	
Cable block		Multiple condition runs	
Constraint & power take-off end stops		Passive yaw implementation	
Body-to-body interactions		Nonhydrodynamic bodies	
Wave directional spreading		Ocean currents	
Parallel computing resources		Wave elevation surface markers	

Growth in WEC-Sim Userbase: Since the release of WEC-Sim v1.0 in December 2014, WEC-Sim has become a popular tool for WEC numerical modeling for many different device types—and even for some nonwave energy applications, as shown by the user map in the left graphic in Fig. 2. Furthermore, a literature review found over 125 publications featuring WEC-Sim between 2013 and 2022, as shown in the right graphic of Fig. 2. Early WEC-Sim publications were led by the code developers NREL and SNL, but in recent years there has been strong growth in external conference and journal articles.

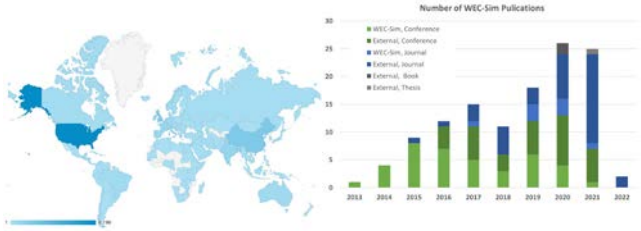

Fig.2 (Left) Google Analytics WEC-Sim users from November 2016 to March 2022. (Right) WEC-Sim publications found from January 2013 to March 2022.

Testing Expertise and Access for Marine Energy Researcher (TEAMER): The U.S. Department of Energy Water Power Technologies Office launched TEAMER [6] with three overarching goals: 1) Improve access to testing infrastructure, 2) improve access to world-class expertise, and 3) provide consistent testing protocols. TEAMER was established to accelerate marine energy technologies to market by streamlining the ability of developers to access the United States' best facilities and expertise through periodic competitive opportunities. The TEAMER facility network covers expertise in 1) numerical modeling and analysis, 2) laboratory and bench testing, and 3) tank, flume, tunnel, and basin testing. Unique to TEAMER is that international

developers and researchers are allowed to apply for support, which opens the door for new collaborations within WEC-Sim. To date there have been nine TEAMER awards focused on WEC-Sim numerical model development to support industry developers and academic researchers. The WEC-Sim TEAMER awards are completed within 9-month time windows and have explored various WEC technologies, including ranging from point absorbers, oscillating surge wave energy converters, oscillating water columns, and an ever-growing list of unique concepts and applications with each request for technical support (RFTS). Most TEAMER awards consist of WEC-Sim model building, model verification/validation, and model documentation to educate applicants on how to use the model for their own needs.

WEC-Sim v5.0 Release: Version 5.0 of WEC-Sim was released publicly at the end of March 2022. This latest release includes a restructuring of the WEC-Sim code for improved readability, updates to PTO-Sim, and improved testing of WEC-Sim branches to identify issues resulting from internal or external code development. The two later updates will be described in greater detail in the following sections.

WEC-Sim v5.0 PTO-Sim: The proper design and study of power take-off (PTO) systems is critical to improve the efficiency and power generation capabilities in WECs. There are two options to model PTO systems using WEC-Sim: the first option is to use a simplified parametric approach in which the PTO is modeled as a linear spring-damper system; the second approach is to model in detail the dynamic interaction of the different parts of the PTO. The PTO-Sim library was created to address the second approach when a comprehensive model of the PTO is needed. PTO-Sim has a variety of blocks that can be used to simulate mechanical or hydraulic drivetrains commonly used in WEC applications. The current version of PTO-Sim is divided into three sub-libraries: Electric, Hydraulic, and Motion Conversion. The sub-libraries have blocks to model electric generators and hydraulic devices such as cylinders, rectifying valves, accumulators, and hydraulic motors, among others. PTO-Sim can be easily coupled with the other WEC-Sim blocks, which allows the user to develop complete wave-to-wire models of the WEC systems. One of the main features of PTO-Sim in the v5.0 release is the versatility of the blocks, which can be used to simulate complex hydraulic or mechanical systems. Users can implement control algorithms using the PTO-Sim blocks inputs as control signals. Examples of using PTO-Sim can be found in the WEC-Sim Applications repository on Github [7]. A hydraulic PTO simulated with PTO-Sim for the RM3 WEC is presented in Figure 3.

WEC-Sim v5.0 Quality Testing and Continuous Integration: A suite of continuous integration tests have been created for WEC-Sim. Deploying a testing suite ensures that future development does not affect the accuracy of WEC-Sim or the functionality of its many advanced features. The testing suite consists of both integration and regression tests. WEC-Sim integration tests check that all application cases run without error or bugs. WEC-Sim regression tests simulate the Reference Model 3 [8] example under a variety of wave conditions and check that the accuracy of the results is unchanged. Certain basic functions have unit tests to check correct functionality. Tests are built on the MATLAB testing framework and run continuously by GitHub Actions. Tests are automatically triggered by pull requests and commits to the WEC-Sim and WEC-Sim Applications repositories; see workflow in Figure 4. Online documentation is also built automatically on commits to the WEC-Sim repository.

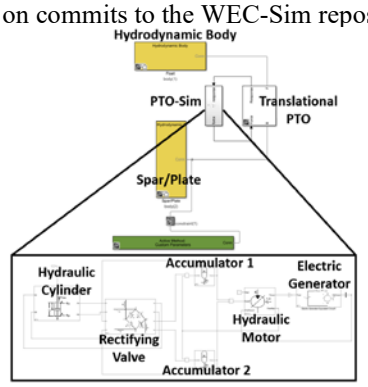

Fig.3 Hydraulic PTO model using the PTO-Sim library.

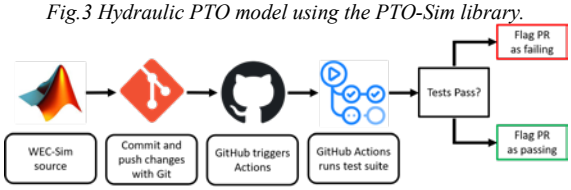

Fig.4 Testing workflow for WEC-Sim continuous interaction schema.

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