Review of WEC-Sim Development and Applications

Yi-Hsiang Yu[#1], Kelley Ruehl [*2], Nathan Tom[#3], Jennifer Van Rij[#4]

[#]*National Renewable Energy Laboratory*
15013 Denver West Parkway, Golden, CO, U.S.A.
[1]yi-hsiang.yu@nrel.gov
[3]nathan.tom@nrel.gov
[4]jennifer.vanrij@nrel.gov

[*]*Sandia National Laboratories*
1515 Eubank SE, Albuquerque, NM, U.S.A.
[2]kmruehl@sandia.gov

I. KEYWORDS

Wave energy converter, hydrodynamics modelling, WEC-Sim, power take-off and multi-body dynamics

II. ABSTRACT

WEC-Sim (Wave Energy Converter SIMulator) is an open-source code for simulating wave energy converters, jointly developed by National Renewable Energy Laboratory and Sandia laboratories in the United States. WEC-Sim is developed in MATLAB/SIMULINK with Simscape Multibody, which solves the multi-body dynamics of the system. A brief overview on the methodology and the capability of the WEC-Sim model will be presented, followed by an investigation on how WEC-Sim was used for different WEC applications.

Typically, as shown in Fig.1, a complete wave-to-wire modelling of WECs involves a combination of wave resources characterization, hydrodynamics, structural dynamics and system dynamics simulations, mechanical and electrical power generations, utilization of control, and grid system simulation. The interaction between these physical problems make WEC design more challenging.

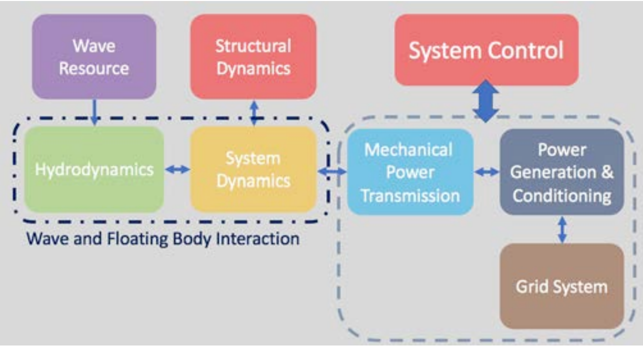

Fig.1 General wave-to-wire modelling components.

WEC-Sim is focusing on WEC dynamics modelling, where the simulations are performed in time domain based on the radiation and diffraction method and using the hydrodynamics coefficients from boundary element method (BEM) based-frequency-domain potential flow solvers (e.g., WAMIT, NEMOH, or ANSYS AQWA) [1]. The governing equations of motion in 6 degrees-of-freedom (system dynamics) are solved at the center of gravity for each body, following Cummins' equation [2], to determine the WEC response. The added mass, wave excitation, impulse response function, and restoring stiffness terms are obtained from the BEM based potential flow solver.

WEC-Sim is developed for the purpose to predict, analyze and optimize WEC dynamics and power performance. Table 1 lists the functionalities of the WEC-Sim model, which are created using prebuilt WEC-Sim blocks (Figure 1) that are developed to be used to simulate a wide range of WEC systems, consisting multiple bodies, water columns, joints, different types of power take-off systems, and mooring systems.

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 Input/Output (BEMIO) functions Nonlinear hydrodynamics Mean drift force calculation			

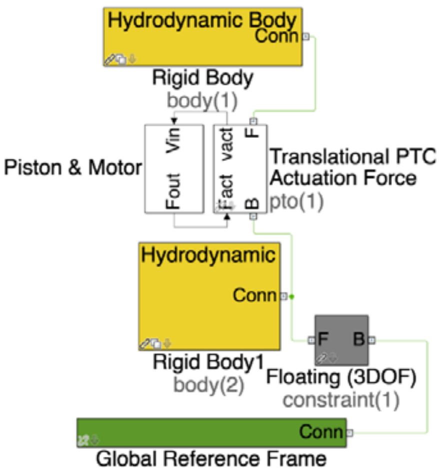

Fig.1 An example of the WEC-Sim model for a two-body floating point absorber device [7].

Like WEC-Sim, linear models are commonly used for WEC simulation, which assumes the body motion and the waves are of small amplitudes compared to the wavelengths. WEC-Sim also allows the use of a weakly-nonlinear method to account for the nonlinear buoyancy and the Froude–Krylov forces induced by the instantaneous water surface elevation and body position [3]. For Mooring dynamics simulation, WEC-Sim is also coupled with a lumped-mass-based mooring model (MoorDyn) to improve its mooring dynamics modeling capability [4]. Recent development included the use of a generalized modes method for evaluating the device hydro-elastic interactions [5] and for simulating flexible WEC designs, and the calculation of mean drift force using momentum conservation principle or the momentum flux approach, which are essential for predicting the wave load for the mooring system and umbilical cables.

The objective of this study is to review how WEC-Sim has been used for different WEC applications. The outcome will be summarized in the categories listed below. A high-level of summary is provided with examples in each category.

Hydrodynamics modelling & performance optimization: WEC-Sim was first developed with a focus on hydrodynamic analysis and WEC power output prediction. WEC-Sim has been used to simulate a wide range of WECs, including point absorbers [6], oscillating wave surge devices [7-8], and oscillating water columns [9]. In addition to simulate a single unit, WEC-Sim has been also used for array performance analysis [9-11]. For example, WEC-Sim was coupled to a mild-slope propagation model MILDwave to analyze the power production of near-shore WEC Array [10].

WEC structure loading analysis: In addition to the implementation of generalized modes method as described in [5], Scriven et al. directly coupled WEC-Sim to a finite element solver to enable coupled hydro-elastic, time-domain analysis [8]. The study revealed that the calculated peak PTO loads was affected by the influence of hydro-elastic interactions. Cruz et al. also used WEC-Sim to look into a series of design situations and obtain estimates of design metrics that define of the loading environment to design a WEC PTO [12].

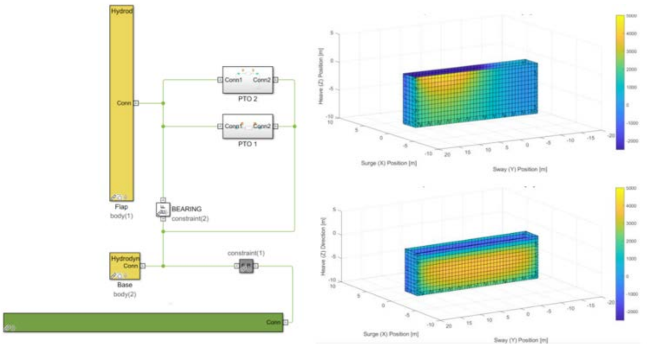

Fig. 2 The MegaRoller WEC-Sim model (left) and examples of the pressure distribution (right) presented by [8].

WEC control applications: Minimizing the loading of a WEC while maximizing power capture across the range of sea states is a challenging task because of the wide distributed frequencies of ocean wave energy. WEC control competition is an open contest, comparing energy-maximizing controllers for WECs, both in simulation and in real time, using a scale device in a tank test situation, with the objective of comparing different WEC control paradigms on a benchmark problem. WEC-Sim was used as the numerical platform for participants to develop their controller for the competition [13].

PTO modelling and grid system analysis: A hydraulic PTO model was developed and coupled with WEC-Sim to evaluate the PTO efficiency for a two-body floating point absorber the trade-off between power output and fluctuation using different power smoothing methods [14]. The WEC-Sim simulation results were then used for a case study to analyse the impact of how WEC-generated power would contribute to a small island electricity system [15].

Other application: In addition to electricity generation, WEC-sim has been used for other application, including wave-powered desalination system for water generation [16] as well as offshore wind applications such as hybrid wind-wave offshore renewable energy systems [17-18].

Many of these applications involve coupling of WEC-Sim to other models, including those for structure dynamics, wave propagation, hydraulic system, and grid system analyses. A better understating on what the open-source model has been applied to and how the modification has been made can be significantly beneficial for open-source code development. Finally, a discussion on potential WEC modelling research areas will be also presented.

REFERENCES

[1] "WEC-Sim (Wave Energy Converter SIMulator)" [Online]. Available: https://wec-sim.github.io/WEC-Sim/.

[2] Cummins W., 1962, The Impulse Response Function and Ship Motions, David Taylor Model Dasin (DTNSRDC).

[3] Lawson M., Yu Y.-H., Nelessen A., Ruehl K., and Michelen C., 2014, "Implementing Nonlinear Buoyancy and Excitation Forces in the WEC-SIM Wave Energy Converter Modeling Tool," 33rd International Conference on Ocean, Offshore and Arctic Engineering, San Francisco, CA, United States.

[4] Sirnivas S., Yu Y.-H., Hall M., and Bosma B., 2016, "Coupled Mooring Analyses for the WEC-Sim Wave Energy Converter Design Tool," 35th International Conference on Ocean, Offshore and Arctic Engineering, Busan, South Korea.

[5] Guo Y., Yu Y.-H., van Rij J., and Tom N., 2017, "Inclusion of Structural Flexibility in Design Load Analysis for Wave Energy Converters," 12th European Wave and Tidal Energy Conference, EWTEC, Cork, Ireland.

[6] Martin D., Li X., Chen C. A., Thiagarajan K., Ngo K., Parker R., and Zuo L., 2020, "Numerical analysis and wave tank validation on the optimal design of a two-body wave energy converter," Renew. Energy, 145, pp. 632–641.

[7] Chow Y. C., Chang Y. C., Chen D. W., Lin C. C., and Tzang S. Y., 2018, "Parametric design methodology for maximizing energy capture of a bottom-hinged flap-type WEC with medium wave resources," Renew. Energy, 126, pp. 605–616.

[8] Scriven J., and Cruz J., 2019, "Introducing non-rigid body structural dynamics to WEC-Sim," 13th European Wave and Tidal Energy Conference.

[9] Bosma B., Brekken T., Lomonaco P., Dupont B., Sharp C., and Batten B., 2019, "Array modeling and testing of fixed OWC type Wave Energy Converters," 13th European Wave and Tidal Energy Conference.

[10] Balitsky P., Quartier N., Stratigaki V., Fernandez G. V., Vasarmidis P., and Troch P., 2019, "Analysing the near-field effects and the power production of near-shore WEC array using a new wave-to-wire model," Water, 11(6).

[11] Boere R., Goudswaard R., Schneider T., and van Vlijmen B., 2019, "Interaction of Ocean Wave Energy Converters," 13th European Wave and Tidal Energy Conference.

[12] Cruz J., Atcheson M., Martins T., Castellini L., and Martini M., 2019, "Preliminary load assessment: UMBRA's 250kW EMG power take-off," 13th Eur. Wave Tidal Energy Conf.

[13] Ringwood J., Ferri F., Tom N., Ruehl K., Faedo N., Bacelli G., Yu Y.-H., and Coe R. G., 2019, "The Wave Energy Converter Control Competition: Overview," 38th International Conference on Ocean, Offshore and Arctic Engineering, Glasgow, Scotland.

[14] Yu Y.-H., Tom N., and Jenne D., 2018, "Numerical Analysis on Hydraulic Power Take-Off for Wave Energy Converter and Power Smoothing Methods," 37th International Conference on Ocean, Offshore and Arctic Engineering, Madrid, Span.

[15] Stefek J., Bain D., Yu Y., Jenne D., and Stark G., 2019, "Analysis on the Influence of and Energy Storage System and its Impact to the Grid for a Wave Energy Converter," 38th International Conference on Ocean, Offshore and Arctic Engineering, Glasgow, Scotland.

[16] Yu Y., and Jenne D., 2018, "Numerical Modeling and Dynamic Analysis of a Wave-Powered Reverse-Osmosis System," J. Mar. Sci. Eng.

[17] Li L., Yuan Z. M., Gao Y., Zhang X., and Tezdogan T., 2019, "Investigation on long-term extreme response of an integrated offshore renewable energy device with a modified environmental contour method," Renew. Energy, 132, pp. 33–42.

[18] Clark C. E., and Paredes G. M., 2018, "Effects of co-located floating wind-wave systems on fatigue damage of floating offshore wind turbine mooring cables," 1st International Offshore Wind Technical Conference, San Francisco, CA, United States.

ACKNOWLEDGEMENTS

This research was completed by the Sandia National Laboratories and National Renewable Energy Laboratory through funding from the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy (EERE), Water Power Technologies Office (WPTO). Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525. NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC under contract No., DE-AC36-08GO28308.