Beta-version Testing and Demonstration of the Design Load Case Generator: A Web-based Tool to Support IEC 62600-2 Standard Design

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Abstract—**International standards for the design, type-classification and certification of marine energy systems, including wave and current energy converters, are essential for the commercialization of these technologies, but their compliance requires significant effort and resources by project developers, e.g., finding the appropriate metocean datasets, processing and analyzing this data to estimate the design load conditions, design type-class and load response. Herein we present efforts to address these challenges by developing, beta-testing and demonstrating a web-based tool, the "Design Load Case (DLC) Generator." This tool integrates a host of data search, processing and statistical tools to streamline the analysis of design load conditions and to determine the design load requirements as in the International Electrotechnical Commission (IEC) 62600-2 design standard. It is demonstrated for a test DLC analysis case for the Reference Model 3 (RM3) point absorber at the US Pacific Wave Energy South Test Site. This test case highlights some of the challenges determining design load requirements and the benefits of facilitating a complex workflow within a single web-based platform that leverages a diverse set of data processing and statistical tools. The DLC Generator facilitates and streamlines DLC analyses for significant time and cost savings on a variety of tasks in a complex workflow, including site data search and retrieval, data quality control, extreme value statistical analyses, and archiving of dynamic load response model inputs and outputs.**

Keywords— **design load cases, IEC 62600-2, wave energy converter (WEC).**

I. Introduction

A previous EWTEC Paper presented the concept for a web-based tool, the "Design Load Case (DLC) Generator," to assist in the design of marine energy systems [1]. The aim of this tool is to alleviate the effort currently undertaken by the device developers to i) find appropriate metocean datasets, ii) collect and process the data, iii) perform statistical analysis to generate design response conditions, and iv) analyse the load response to determine the load requirements that satisfy the International Electrotechnical Commission (IEC) 62600-2 design technical specification [2].

Each of the steps required to generate the Design Load Cases can be challenging. For example, metocean data is provided by multiple buoy datasets, including NOAA [3], CDIP [4], and the US Department of Energy's (USDOE) model hindcast data hosted by the National Renewable Energy Laboratory (NREL) [5]. Each of these sources structures the data differently and has separate interfaces for access. Similarly, performing the data analysis requires either the development of custom routines or leveraging open-source software, both of which can be time consuming. The DLC web-tool removes these complexities by providing a consistent interface to work with the

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metocean data and including a wide array of high-level options to perform analysis, leaving the detailed implementation to the tool. This approach should lead to significant time savings for marine energy developers.

This paper highlights the testing and demonstration of the DLC Generator tool, including a description of the software implementation, the tool's user interface (UI) and functionality, via a design load case analysis case study of the Reference Model 3 (RM3) point absorber wave energy converter (WEC) [6] at the PacWave South test site. A beta version of the DLC Generator with features outlined in [1] has undergone internal testing, followed by alpha testing with a select group of users. A wider pool of users will be invited to conduct beta testing before the tool is released publicly.

II. Methods

A. DLC Generator Overview

A high-level view of the DLC generator is shown in Fig. 1, summarising the overall workflow of the tool. The tool is accessed via the internet and standard browsers.

The user first selects the metocean data for the location of interest. The DLC Generator then provides visualisations of this data along with parameters to perform data cleaning. Once the data has been cleaned, statistical analysis is undertaken to allow the user to select representative energy period, T_e, and significant wave height, H_{m0}, for the 1- and 50-year sea states, in accordance with IEC 62600-2.

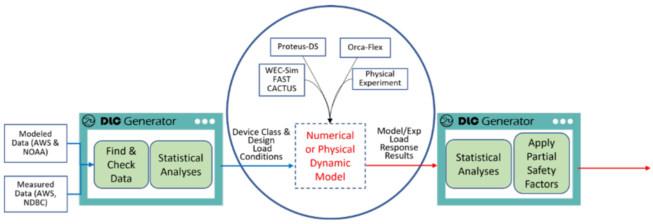

Fig. 1 Overall workflow for the DLC Generator

The developer can then download time series realisation of these sea states to use as an input to either physical or numerical model testing. The time series of the device's properties of interest, such as loads or motions, can then be re-uploaded into the DLC Generator which performs an extreme value analysis to characterize these response properties. The final output of the DLC Generator is a report summarising the inputs and outputs of the analysis.

B. Software Architecture

The DLC Generator has been designed as a modular system to maximize the ease of maintenance for the lifetime of the project. The tool is hosted using Amazon Web Services (AWS) which provides the "instances" (virtual computers) to run the tool alongside several standard components (described below) to store data and provide user access control.

The overall architecture of the DLC Generator is shown in Fig. 2. Security is a paramount concern. When a user accesses the DLC Generator using a user interface in their browser, the request is directed to the AWS "API Gateway": the gateway first verifies the user is authenticated using the AWS "Cognito" user management system. As both these tools are developed and managed by AWS itself, there is a high degree of confidence in their security. Once the request from the user has been authenticated, the "API Gateway" forwards the request to the "Coordinator" module. The "API Gateway" and "Cognito" components of the system are the only parts that are accessible from the public internet.

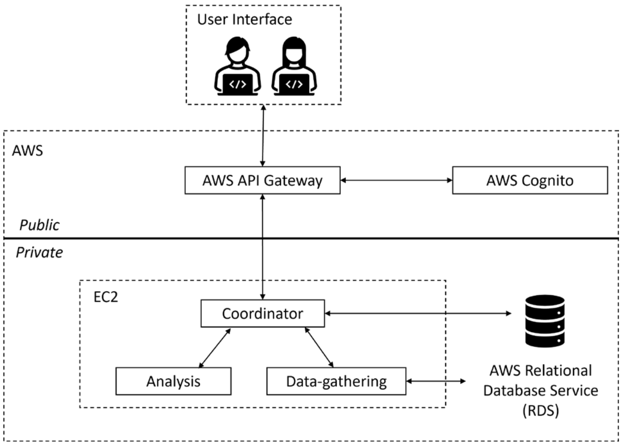

Fig. 2. Schematic of the DLC Generator software architecture

The user interface (UI) gives the user access to the functionality of the DLC Generator via their standard web browser. It has been implemented by the DLC Generator team using the React framework in the JavaScript programming language and uses many similar features found in modern websites. Data for the UI is requested via HTTPs to ensure that all data is encrypted between the AWS environment and the user. A description of the experience of the UI is provided in a later section.

Persistent storage for the DLC Generator is provided by the AWS Relational Database Service (RDS) running a PostgreSQL database engine. This arrangement means that AWS manages the running of the database with the DLC Generator team having full control over the layout and querying of the data.

The three modules developed specifically for the DLC Generator are the "Coordinator," "Analysis" and "Data-gathering" modules. Each of these runs as a separate process on a single AWS EC2 instance and communicates via HTTP APIs. The job of the "Coordinator" is to route requests from the UI to the appropriate service. Data related directly to the UI experience, such as the location the user has selected for analysis, are retrieved directly from the database whereas requests for analysis or new data are forwarded to their respective module. The "Coordinator" is implemented in the Go programming language, which is well suited to writing web servers.

The "Analysis" module provides routines for performing statistical analysis on the data, implemented in the Python programming language. The DLC Generator leverages the routines available in the open source MHKiT package [7], which has been developed as a collaboration between the National Renewable Energy Laboratory (NREL), Pacific Northwest National Laboratory (PNNL), and Sandia National Laboratories (Sandia, SNL). In addition, the ViroCon package [8] is also used for the computation of environmental contours. Making use of this open-source functionality has not only reduced the development cost for the DLC Generator but also enables the tool to benefit from improvements made by the wider community. As part of the DLC Generator project, several improvements to MHKiT have been made by the DLC Generator team.

The "Data-gathering" module is responsible for identifying and retrieving the metocean data user's request. At present, data from the NDBC and CDIP buoy databases, and the USDOE one- and three-hour hindcast are available. Where the need arises, the system has been designed to easily incorporate additional datasets.

The "Data-gathering" module also makes use of the functionality provided by MHKiT. The process for accessing the USDOE hindcast data requires the use of a Highly Scalable Data Service (HSDS) server. An HSDS server is provided by NREL but has limits in place for the amount of data that can be accessed. The DLC Generator runs its own HSDS server without these restrictions, making the data more accessible to developers.

The total combined data in these datasets is infeasible for the DLC Generator to store internally. Instead, a hybrid strategy is used based on the likelihood that some locations (such as demonstrator test sites) will be investigated more than others. When a location is first requested, the data is fetched from the original source but on subsequent requests (by any users) the data will quickly be loaded from the DLC Generator's own internal database.

The resources required to run the DLC for tens of users is small. A single 2CPU, 8GB of RAM EC2 instance (t2.large) powers the "Coordinator", "Analysis" and "Data-gatherer" modules and the database is an RDS instance with 2CPUs and 2GB of RAM (db.t3.small). The "API Gateway" and "Cognito" are provisioned by AWS and will automatically scale to deal with the number of requests made by the users. An advantage of using these AWS services is the ability to increase computing power as the number of DLC users grows.

C. *Alpha testing*

A select group of WEC developers and academics unfamiliar with the DLC Generator were invited to use the tool. Each tester was provided with a feedback sheet by the DLC team for every step of the process. This feedback was accessed by the DLC Generator team leading to several improvements in the workflow. New feature requests have also been recorded and may be implemented if other users as part of the upcoming beta testing also believe the feature to be useful.

III. CASE STUDY

A. *Overview*

A similar case study to [1] is performed at the PacWave South test site (44.568N, 124.229W) for the Reference Model 3 (RM3) point absorber. All images that follow are screen shots from a developer's internet browser using the actual DLC Generator.

B. *Site Location and Data Selection*

The first page of the DLC Generator enables the user to create a new 'Project.' Projects are persistently stored to allow the user to come back to them later. Once a project is created, the first step is to select the location as shown in Fig. 3.

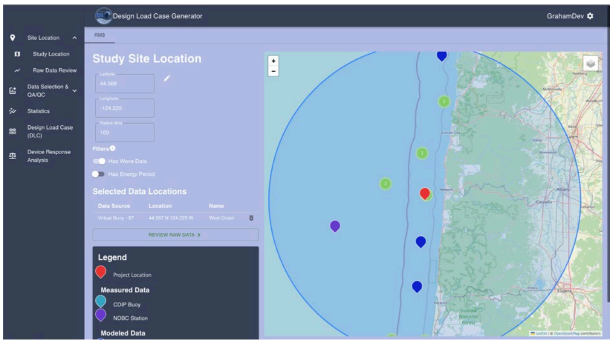

Fig. 3 Site Selection using longitude and latitude, showing all data sources within a selected radius.

The user can either enter the longitude and latitude or drag the red marker to a location on the map. In this case the user has entered the longitude and latitude corresponding to the PacWave South site. Immediately, data sources within a user selected radius of the project location are displayed. CDIP data locations are indicated by a turquoise marker, NDBC data locations by purple markers and hindcast data by a blue markers. Where there are multiple data sources in proximity, a green circle marks the location, indicating the number of points. Clicking an individual data source brings up detailed information as shown in Fig. 4, such as the period of record (POR) and the water depth.

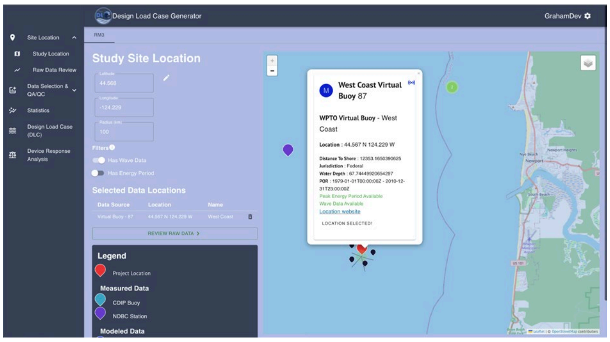

Fig. 4 Detailed information displayed when clicking on an individual data source.

For the purposes of the case study, the user has only selected the USDOE hindcast West Coast Virtual Buoy 87 as the data source, though multiple sources can be selected.

The next section in the DLC Generator allows the user to view the raw data from the selected data sources. Fig. 5 shows the data viewed as a H_{m0} against T_e scatter plot.

Fig. 5 Scatter plot of the raw data showing H_{m0} against T_e for Virtual Buoy 87

C. Quality Control

The raw data (particularly from buoys) may contain spurious data (such as e.g., $H_{m0} > 50m$). The Quality Control screen provides options to 'clean' each of the H_{m0}, T_p or T_e data based on

- Values for corrupt data, e.g., -999,
- Maximum and minimum values,
- Changes within a given window to detect either stagnation or abrupt changes,
- Outliers as defined by given number of standard deviations from the mean.

This functionality leverages the MHKiT 'qc' module.

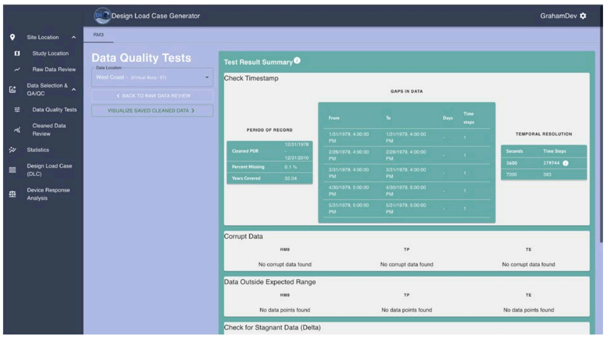

Fig 6 Results from the Quality Control step

Running the Quality Control returns the summary in Fig 6, in which the gaps in the record are automatically detected and the number of samples removed are shown. The 'cleaned' data can be viewed in the same manner as the raw data; the points removed in the time series and scatter point are explicitly marked.

D. Statistics

Having obtained 'cleaned' data, the next step is to compute the 1- and 50-year representative sea states, corresponding to IEC TS 62600-2 recommendations. The DLC Generator supports both univariate and bivariate (contour) methods.

The univariate methods, described by [9], include Generalized Extreme Value Annual Maxima, Generalised Pareto Peaks Over Threshold, Weibull and Weibull Tail distributions using the functions in the MHKiT 'loads.extreme' module. The user is presented with a Q-Q plot for each of these distributions to select the 'best fit'.

For this case study, the use of the of bivariate methods is demonstrated. The bivariate methods take the form of a Inverse First Order Reliability Method (IFORM) contour applied with probability functions of Principal Component Analysis (PCA) [10], Gaussian [11], and the global method referred to herein as 'OMAE2020' [12]. MHKiT provides the first two methods, and ViroCon the latter. Fig 7 shows the three contours for the 50-year return period plotted over the data. A similar process is undertaken for the 1-year contour.

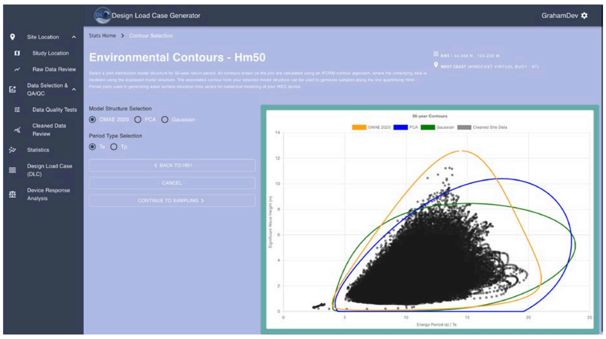

Fig 7 Contours for the 50-year design condition

E. Sea State Realisation

The user now selects which contour to proceed with, in this case the OMAE2020 model is selected. The next step in the DLC Generator is to sample the contour for the representative sea states. Fig. 8 shows the selection process which includes the choice of spectrum (JONSWAP or Bretschneider), the time series length and sample rate, and the seed to generate random phasing for reproducibility. The selected sea states are then generated, plotted, and can be downloaded by the user into a CSV file.

Sea states that cover the contour peak with (T_e, H_{m0}) = (13.06, 12.12), (14.06, 12.52), (15.06, 12.51) and (16.06, 11.97) (s, m) are selected herein for response analysis.

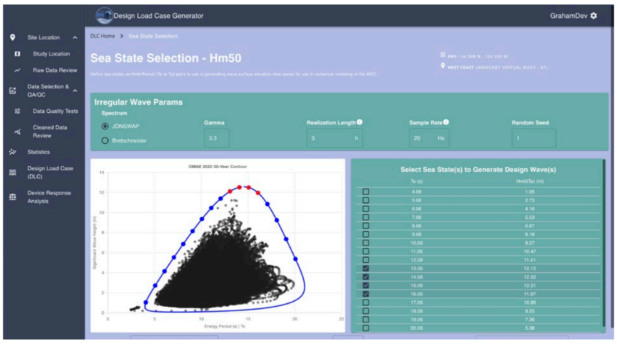

Fig. 8 Selecting the sea states from the contour, the red points indicate which sea states have been selected for simulation.

F. RM3 WEC-Sim Model

This case study uses the numerical model WEC-Sim to simulate the response of the full-scale RM3 WEC (included with WEC-Sim as an example case). To characterise the response of the RM3 model in the 50-year sea state, a single 18-hour simulation was undertaken for each sea state, and then divided into six 3-hour sections to comply with minimum requirements in the IEC TS 62600-2. For the purposes of this case study, the PTO responses have been used, with two responses of interest: i) the force on the PTO, ii) the PTO extension (or position). The simulation parameters are summarized in the Appendix.

The WEC-Sim model is identical to that used by Neary et al. [1]. It is noted that WEC-Sim modeling is only one of many different methods that can be used to obtain the device load response. Other possible candidates include ProteusDS, Orca Flex, or physical wave tank model experiments. The method to be adopted in practice depends on a number of factors, including the complexity of the device, model accuracy requirements and the severity of the sea state conditions. Numerical modelling approaches for WECs are detailed in Folley [13], including nonlinear potential flow models and CFD models, both of which go beyond the inviscid and irrotational (potential flow) boundary element modelling simplifications within WEC-Sim. Despite WEC-Sim's limitations, particularly in severe non-linear sea states, WEC-Sim is applied in this test case for the purpose of demonstration.

G. *Response Analysis*

Following the simulation using the WEC-Sim model, the six 3-hour time-histories of the PTO force and the PTO position are uploaded back into the DLC Generator. This upload process can be done either using a CSV file or using the NetCDF format. The file format required for the NetCDF upload is outlined in the online documentation for the tool.

The response analysis is performed using the 'short_term_extreme' function from the MHKiT 'load.extreme' module. More detail on estimating short term extremes can be found in [11]. In this case, the Peaks Over Threshold method is used to fit the peaks for the extreme distribution.

Table 1 shows the results of the load response analysis.

The design load case (DLC) has a safety factor of 1.35 in accordance with IEC TS 62600-2. The 'Characteristic Extreme Avg' column refers to the mean of the maximum value over each of the six 3-hour sections. The maximum responses for both the PTO force and extension are very close between the four sea states chosen. In this test case, the maximum response correlates with the maximum significant wave height. However, this may not always be the case, indicating the value of using a contour method in which several values around the peak can be simulated or tested in a physical model test.

IV. CONCLUSION

The case study herein demonstrates the use of the Design Load Case Generator web-tool to perform a load analysis of a WEC. One key benefit of the DLC generator is the ability to quickly identify the relevant data sources for metocean data and then to have confidence in the analysis that follows. The time savings to WEC developers will be significant.

If a different data source were desired, the user would simply return to the first page of the tool to select, say, an NDBC buoy. The user is not required to rewrite any custom data analysis scripts to handle the new data source. The user could then compare the results of various data sources (e.g a hindcast result and a buoy observation) before proceeding with numerical simulations or physical tank testing. Furthermore, as new data sources are added to the DLC Generator, WEC developers can immediately benefit from the new data.

The DLC Generator team will be collecting feedback from the beta testing and will remain receptive to input when the tool is made available more widely. It is anticipated that the following areas of future work will be fruitful:

- Integration of more data sources, such as NOAA hindcast,

TABLE 1
RM3 RESPONSES AT PACWAVE SOUTH SITE

Bivariate (Contour)							
Response	***Sea State (T_e (s), H_{m0} (m))***	***Range***	***Mean***	***Stdev***	***Characteristic Extreme***	*DLC ($\gamma_f = 1.35$)*	***Characteristic Extreme Avg***
PTO Force *(MN)*	(16.06, 11.97)	[-4.9, 5.2]	-5.6e-5	1.1	4.7	6.3	4.5
	(13.06, 12.12)	[-5.1, 5.3]	-1.2e-5	1.3	5.1	6.9	5.1
	(15.06, 12.51)	[-5.4, 6.2]	-2.2e-5	1.2	5.1	6.9	5.1
	(14.06, 12.52)	[-4.9, 5.8]	3.0e-5	1.3	5.4	7.2	5.3
PTO Position *(m)*	(16.06, 11.97)	[-6.4, 12.3]	1.2	1.9	11.0	14.8	11.4
	(13.06, 12.12)	[-6.0, 14.1]	1.3	2.2	11.9	16.1	11.7
	(15.06, 12.51)	[-6.3, 14.4]	1.4	2.1	12.1	16.4	12.1
	(14.06, 12.52)	[-6.7, 13.4]	1.4	2.2	12.3	16.6	12.1

- Including other metocean parameters such as current,
- Including more statistical methods such as the calculation of highest density contours,
- Increased ability for users to download data at intermediate stages of the analysis process.

APPENDIX: WEC-SIM PARAMETERS

- Wave Type = 'irregular'
- Wave Spectrum Type = 'JS'
- Wave BEM Option = 'EqualEnergy'
- Wave Phase Seed = 1
- Float Mass = 'equilibrium'
- Float Inertia = [20907301, 21306090.66, 37085481.11]
- Spar Mass = 'equilibrium'
- Spar Inertia = [94419614.57, 94407091.24, 28542224.82]
- PTO Stiffness = 0
- PTO Damping = 1200000

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