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SEAGRID: A New Dynamic Modelling Tool for Power System Analysis of Ocean Energy Devices

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Abstract

As the ocean energy industry approaches commercial readiness, there will be a greater focus on integration of ocean energy devices (OEDs) into the electrical power system network. Device developers will be required to provide dynamic models of their device for grid connection, and ensure their device operates within the limits laid out in the grid code. Project developers will need to assess the impact of different wavefarm configurations, ratings for the electrical equipment, power losses, and performance during a fault. Grid operators will require dynamic models to investigate the impact an OED will have on the grid and also for future grid planning studies.

The SEAGRID dynamic modelling tool attempts to address each of these issues using its generic modelling approach. The SEAGRID model is capable of producing a scalable time domain power system dynamic model using empirical test data and component specifications, bypassing the need for a full hydrodynamic study of the device.

Keywords: generic modelling, grid integration, dynamic modelling, power systems

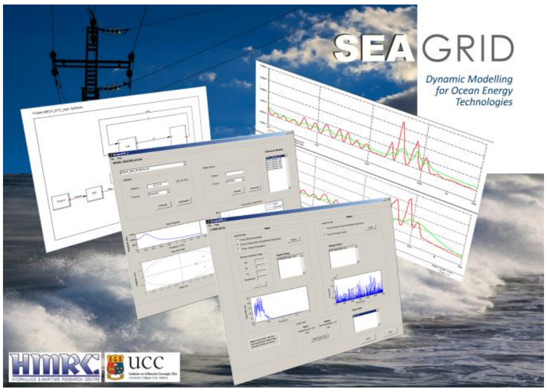
1. Introduction

Dynamic models will be an important requirement for grid connection of ocean energy devices. As the ocean energy industry approaches commercial readiness, the creation of dynamic models for power system studies will become more prevalent. Many grid codes currently specify that an electricity generating plant must provide a power system dynamic model for grid connection to be granted [1,2]. Grid operators use power system dynamic models to simulate the time-varying power output of a device under different resource conditions, and assess the impact a device will have on the grid, under both normal and faulted conditions. They are necessary to prove to the grid operator that the connection of an OE device does not impact negatively on the operation of the grid, and produces acceptable power quality. For the device developer, dynamic models may be used to determine whether any remedial design work is required in order to procure a grid connection.

When large scale wind energy was being introduced to electrical networks, dynamic models were being supplied by wind turbine manufacturers and software vendors. These models were typically highly proprietary ‘black box’ type models, which led to a number of issues for grid operators such as model instability and debugging difficulties.

Furthermore, with a large number of models, it became difficult to ascertain the quality of each individual model. The experiences of the Irish grid operator, Eirgrid, with dynamic models for wind turbines are described in [3].

Due to the issues with individual proprietary models within the wind industry, there is now a movement towards developing generic models for wind turbine generators [4,5]. The SEAGRID project was initiated in 2009 in anticipation of the future need for generic dynamic models for ocean energy devices.



This paper presents the SEAGRID tool for dynamic modelling of ocean energy devices. Generic modelling of ocean energy devices will be discussed, along with a brief overview of the SEAGRID model and some of its modelling capabilities.

2. Generic Dynamic Modelling

As part of the development process, many device developers use simulation models to gain a better understanding of their device and to optimise certain device parameters or control algorithms. These models can be quite complex and contain a large number of parameters. Such level of detail is not required for power system dynamic models; power system studies typically take place over a short time period (<30secs) so in this case modelling the electrical system (generator, power electronics, controllers etc) would be more important than the front end of a device (e.g. the wave/device hydrodynamic interaction). Furthermore, these models are often proprietary and require large amounts of input data, making them unsuitable for power system studies.

One approach to overcoming these issues would be through the creation of generic dynamic models. These generic models would consist of a common structure for all device types, customisable by device-specific parameters. There are numerous benefits to this generic modelling approach for a variety of interested parties. Device developers could tune the model parameters to best represent their equipment without having to reveal proprietary information; grid operators would have more confidence in the stability of their models, and would give them a greater flexibility in their grid planning studies; generic models could also facilitate comparative/optimisation studies for different device types and parameter settings.

However, these benefits can only be realised if the generic models can adequately simulate the relevant dynamics for all device types. This is the biggest challenge in developing generic models.

Within the wind industry, progress has been made towards creating generic models for wind turbines. Groups such as WECC Wind Generation Modeling Group and the IEEE Working Group on Dynamic Performance of Wind Power Generation have been engaged in research in this area for the past number of years. Furthermore, a new IEC standard (IEC 61400-27) for generic simulation models for wind power generation is currently in development. The working group for this standard consists of a range of parties involved in the wind industry, including manufacturers, grid operators, project developers, software developers and research institutions.

“The purpose of IEC 61400-27 is to define standard, public dynamic simulation models for wind turbines and wind power plants, which are intended for use in large power system and grid stability analyses, and should be applicable for dynamic simulations of power system events such as short circuits (low voltage ride through), loss of generation or loads, and typical switching events (e.g. line switching).” [5]

Four types of wind turbine technology have been identified for generic modeling – Type 1: Induction generator; Type 2: Induction generator with variable rotor resistance; Type 3: Doubly-fed induction generator; Type 4: Asynchronous or synchronous generator with full convertor interface.

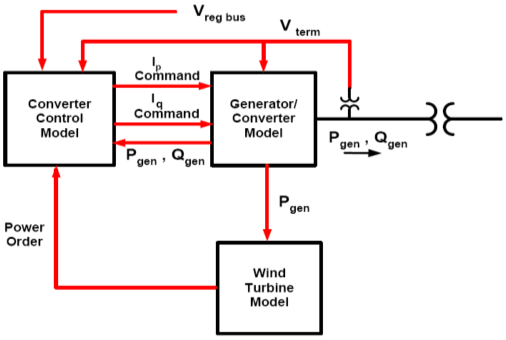


Figure 1: Generic WTG Model Type 4 [4]

Based on the lessons learned from the dynamic modelling issues encountered by the wind industry in the grid integration process, it is envisaged that the ocean energy industry could benefit greatly from the creation of generic models. Generic modelling for ocean energy is perhaps considerably more complicated due to the diverse range of ocean energy power conversion mechanisms (e.g. oscillating water column, point absorber, overtopper, tidal turbine etc). No device type has yet proven to be superior; it is quite likely that a number of device types will be deployed on a large scale in the future. An ocean energy generic model will need to account for this.

An initial investigation into ocean energy generic modelling was undertaken in [6]. Furthermore, a study, looking into the generic modelling approach for ocean energy convertors, was undertaken in 2010 as part of Annex III of the International Energy Agency – Ocean Energy Systems (IEA-OES) Implementing Agreements [7]. The study included a survey of 35 ocean energy device developers, which looked at general device configurations and types of data collected by these developers. The outcome of this study was an initial generic model structure, of which formed the basis of the SEAGRID model, as outlined in [8].

3. SEAGRID Model

The SEAGRID model is a generic dynamic model which describes the main power flow conversion from wave power to electrical power. As with all generic models, a number of simplifications are made. The hydrodynamic equations are replaced with a transfer function. This transfer function is obtainable through system identification techniques using empirical test data. Power take-off (PTO) is modelled using a number of simplified generic mechanisms.

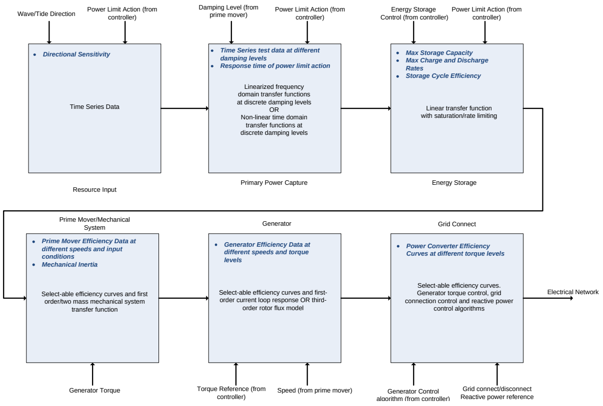


Figure 2: SEAGRID Model Overview

The model is constructed in the DIgSILENT PowerFactory power system simulation software. In PowerFactory, the generic model is linked to an electrical network which represents the device's electrical system (including power electronics) and the electrical grid.

For the following test case, empirical data from a ¼ scale floating oscillating water column device was scaled up and used to generate the parameters required for the SEAGRID generic model. An overview of the PTO system is shown in Figure 3. A transfer function for the wave-pneumatic power conversion, i.e. the primary power capture (PPC), is derived using empirical test data. The conversion from pneumatic power to the turbine's mechanical power is determined within the prime mover unit (PMU) block, using the turbine's performance characteristics.

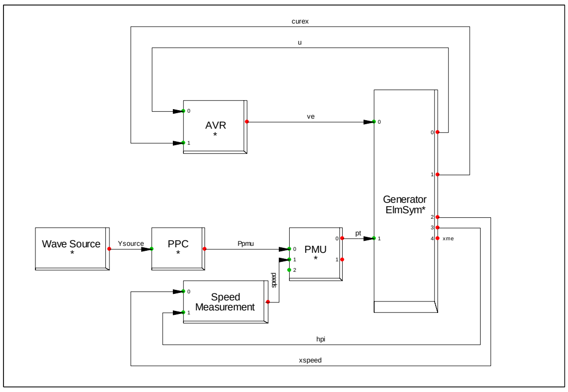


Figure 3: PTO Overview

The scaled test device was not grid connected, so for modelling purposes, a suitable electrical system was sized to correspond to the device. The chosen electrical system was a synchronous generator connected to the grid via a back-to-back PWM convertor. The single-line diagram for the electrical system is shown in Figure 4.

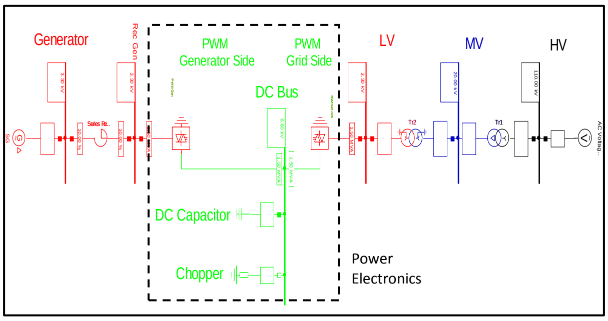


Figure 4: Electrical Network

The SEAGRID model also contains a number of options for control of the generator and power electronics. For this simulation a simple speed control algorithm was used to control the generator speed; the reactive power is controlled using a PI algorithm on the grid side PWM convertors. Power and voltage from the generator and grid are input to the generator-side and grid-side PWM controllers, respectively. These controllers set the reference currents for both PWM converters. This model also contains protection mechanisms to protect the system in the case of a grid fault. An overview of this system is shown in Figure 5.

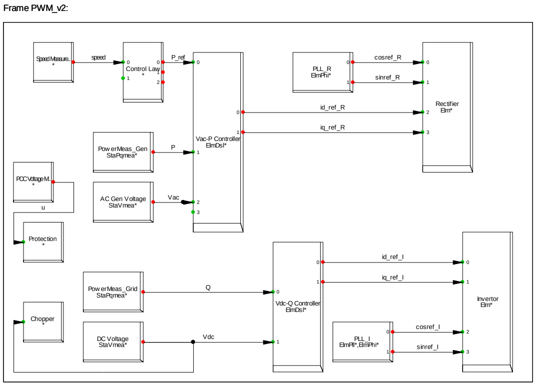


Figure 5: Electrical System

The following graphs are initial results using the SEAGRID generic model. Figure 6 shows the power smoothing as the OWC's pneumatic power is converted to electrical power. The effects of the power electronics and controls are seen by the relatively smooth electrical power output (shown in blue).

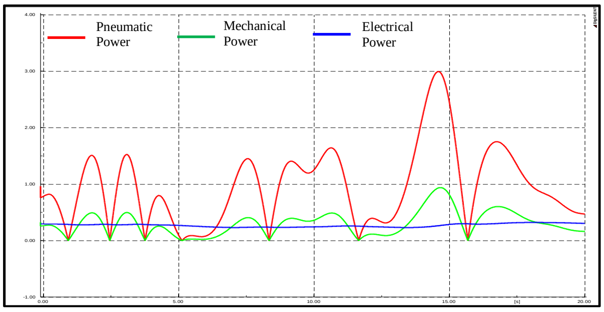


Figure 6: Power Conversion

Furthermore, despite the pneumatic power being quite erratic, the generator speed is relatively steady, as shown in Figure 7.

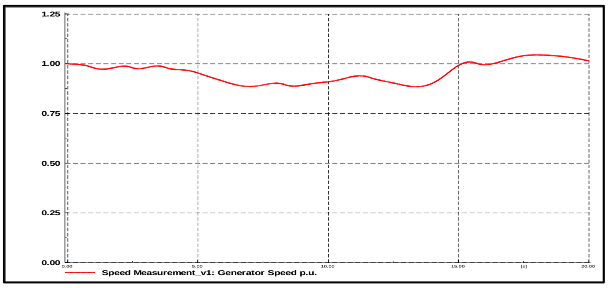


Figure 7: Generator speed

The SEAGRID model can simulate a range of electrical configurations, such as synchronous/asynchronous generators; direct grid connection/grid connection via power electronics, and a number of common electrical control configurations. Electrical faults can also be simulated quite easily in the PowerFactory model. Figures 8 & 9 show how the voltage and reactive power control responds after a short-circuit fault is applied to the HV busbar.

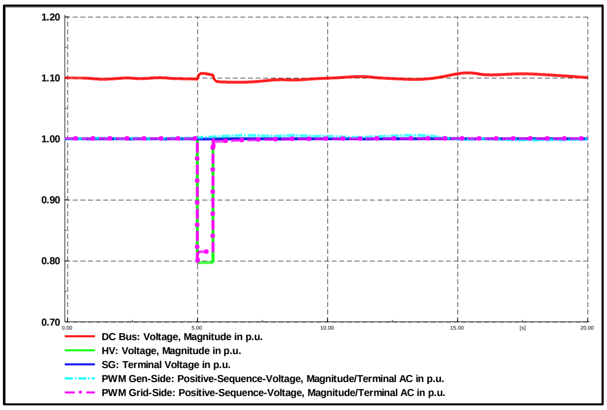


Figure 8: Voltages

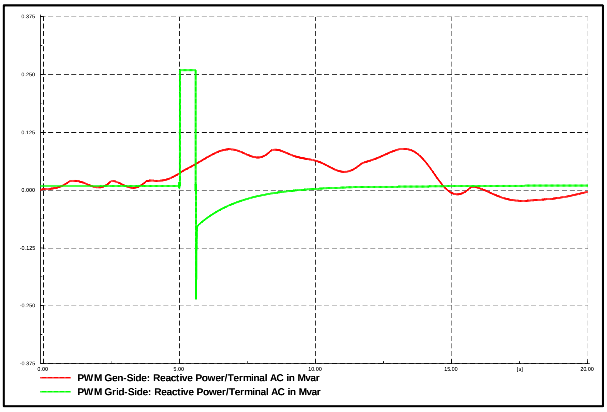


Figure 9: PWM Reactive Power

4. SEAGRID Modules

With regards to grid integration, the ocean energy industry will consist of a number of stakeholders – device developers, project developers and grid operators. Each stakeholder will have different interests in terms of dynamic modelling. Device developers will be required to create dynamic models for power system studies and will be interested in seeing how their device performance compares to the grid code requirements. Project developers may want to look at how a wind farm performs, and investigate whether the costs of the electrical system can be reduced. Grid operators may want to investigate how generic ocean energy device types interact with the grid as part of planning studies. For these reasons, SEAGRID contains different modules which focus on the needs of the various stakeholders.

Dynamic model creation

The detail level of data entry can be selected by the user; two options exist where the developer may enter precise details of their device such as device specifications, test data, machine parameters and control configurations via the Device Specific Dynamic Model Tool. This data is processed and relevant parameters are exported for use in the generic dynamic model.

Alternatively, the user may select the Generic Dynamic Model Tool, which enables the project developer to create dynamic models for a range of generic device types without the need for OE device specifications or test data. user may select a device from a range of wave and tidal devices, without the need to enter specific device details.

Electrical design tool

The GUI application also incorporates an electrical design tool to provide guidelines on cable sizing, transformer and compensation options, cable and transformer losses, fault current profiles and other important design information.

Grid compliance

This feature provides an automated methodology to ensure that the OE device is grid compliant with the Grid code requirements. SEAGRID supports the grid codes of Ireland and the UK, and the ENTSO-E grid code requirements which will define the guidelines for Europe in the near future.

5. Conclusions

Generic power system models for ocean energy could play an important part in easing the integration of ocean energy devices onto the electrical grid. Device developers, project developers and grid operators could benefit greatly from the provision of such models. Due to the diverse range of ocean energy devices, one generic model for all device types would not be feasible; instead it is likely that a number of generic models will be developed for each device type & electrical configuration – e.g. point absorber, overtopper, oscillating water column. The main challenge in developing these models will be in simplifying the front-end power conversion, whilst maintaining the model's accuracy of the electrical output.

This paper has shown how a generic structure for one device type can be used to simulate the dynamic performance of an ocean energy device's electrical system under normal and faulted conditions, using only experimental test data and a number of key parameters. The SEAGRID modelling tool currently contains generic structures for a number of device types and has a range of uses for device developers, project developers and grid operators.

6. Further Work

The current SEAGRID model has undergone an initial proof-of-concept phase. Current and future research focus is on the further refinement of the SEAGRID model, making it more robust to allow for more device types and configurations. The next phase of the project will have a particular emphasis on modelling device aggregation, and also on model validation which will be a crucial task in SEAGRID's development progression.

7. Acknowledgements

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