Sandia National Laboratories

PTO-Sim White Paper

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Executive Summary

The PTO-Sim module is an integral component of the WEC-Sim project, which is an open-source numerical simulation tool to analyze the dynamic response and power performance of wave energy converters (WECs) subject to operational waves. The power take-off (PTO) (also referred to as the power conversion chain, PCC) is a part of the device which converts useful mechanical motion into electricity. Over the past couple of decades a wide variety of WECs and PTOs have been conceptualized and patented. In order to create baseline models for the PTOs, the WECs need to be categorized based on their energy conversion mechanism. Nearly all WECs convert energy from the wave into either relative linear motion, relative rotary motion, or fluid capture. The power transmission connects this useful mechanical energy to the electrical generator. Most wave energy developers have preferred to use a hydraulic drivetrain. Recently, however, a mechanical drivetrain, similar to the ones developed by the wind industry are gaining popularity. If the WEC uses fluid capture as the energy conversion mechanism, then the power transmission must consist of a turbine. The electrical generators must be fully or partially buffered from the grid by power conditioning equipment. Thus, each of these components is an integral part of the power conversion chain and should be modeled accordingly. For the first iteration of the WEC-Sim project, we recommend not to model fluid capture devices because of the large disparities between these devices and the rest of the WECs. The model will include a few representative geometries and power transmissions (including hydraulic and simple mechanical drivetrains) in order to estimate the power output of a WEC.

Contents

1 Project Scope

1.1 Module Purpose

WEC-Sim is a DOE funded project to develop an open source wave energy converter (WEC) modeling tool. The code's development is a joint effort between SNL and NREL to develop a WEC wave-to-wire model that determines a WEC's dynamics response and power performance when subject to operational waves. SNL has been tasked with development of PTO-Sim, a module in the WEC-Sim code that simulates a WEC's power conversion chain (PCC), also refered to as the power take-off (PTO). This module represents the transformation from the mechanical energy of the device (either potential or kinetic energy) to other, more useful forms of energy, such as electrical current or high-pressure fluid. Development of WEC-Sim must be versatile enough to account for the diversity of WECs archetypes. Similarly, development of PTO-Sim must be able to account for the diversity of existing WEC PCCs. The function of the PTO-Sim module within the larger WEC-Sim framework is shown in Fig. 1. At each time step, the 6-DOF solver determines the dynamics for each of the WEC bodies. This information is then fed to the PTO-Sim module. Based on the configuration of the PTO, the module returns forces and/or moments to be applied to the device and outputs power. The instantaneous power at different stages in the PCC can be calculated, thus allowing the user to compare available power to extracted power in order to better understand overall device performance. Thus, a wave energy developer can try out various pre-designed PCCs to optimize the power output of their WEC. Likewise, the same PCC can be attached across many wave energy devices in order to determine which device geometry is optimal for a given certain sea state or incident wave.

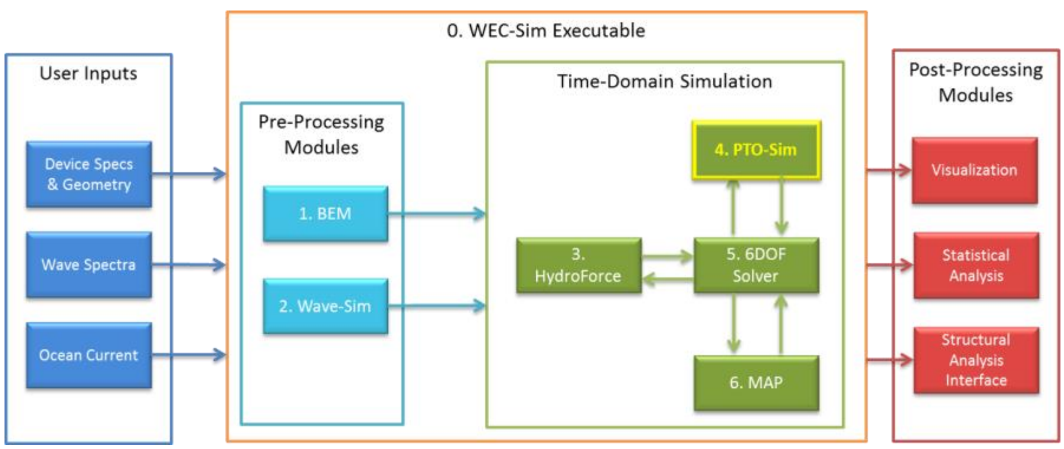

Figure 1: WEC-Sim code structure, with the PTO-Sim module highlighted, (adapted from [1], emphasis added).

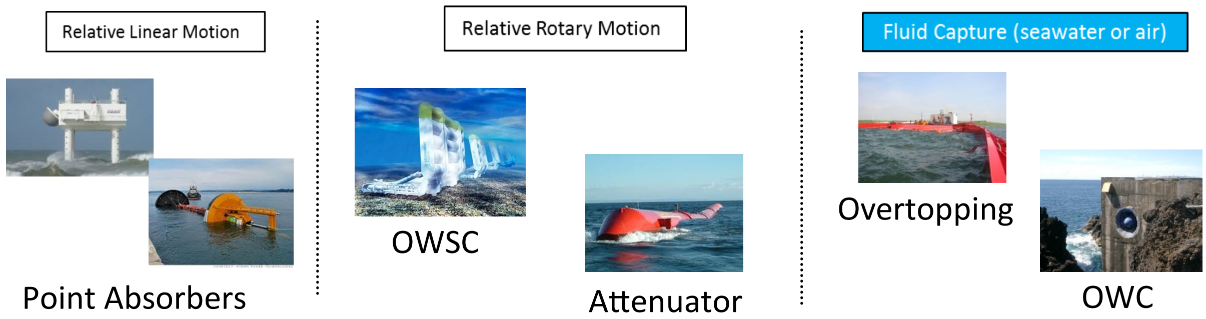

Figure 2: WECs grouped by energy conversion mechanism.

2 Types of WECs and Energy Capture

The power conversion chain begins with the WEC capturing the kinetic and potential energy from the wave. Over the past 40 years of development in the wave energy industry many different types of WECs have been designed. For our purposes we will group them depending on the energy conversion mechanism: relative rotary motion, relative linear motion or fluid capture (such as, seawater or air), as shown in Fig. 2. Examples of types of WECs that produce relative rotary motion include *oscillating wave-surge converters*, *attenuators* and *terminators*. A type of WEC that produces relative linear motion is a *point absorber*. Examples of types of WECs that capture fluid include *oscillating water columns* and *overtopping devices*.

Over the past few decades PCC technology for wind turbines has made significant advances. Though very few WECs have been grid connected thus far, we can draw many similarities between wind turbines and WECs. One of the most challenging aspects of energy conversion in these fields is the high variability of rotor speed due to the stochastic nature of the resource. At first, wind engineers tried to solve this problem by forcing the wind turbines to spin at a constant speed. Developers soon realized, however, they could increase the efficiency of the turbines significantly if the rotor could spin at varying speeds. Likewise, since a WEC placed in the open ocean is subject to waves of different periods and amplitudes, tuning the device to the predominant wave period changes the frequency of oscillation of the device. For this reason, among many others, we will draw insight into the power conversion process for a WEC from the onshore and offshore wind energy industry. Thus, much of the generator portion of the power conversion chain, discussed in Sec. 5.1, comes from lessons learned from the wind energy sector. Further, the computer aided engineering tool for the analysis of wind turbines from NREL, known as FAST, includes a model of an induction generator. This generator model can be used as a good basis for the WEC-Sim project. Additional details and subsystems, including power electronics can be added to the model in the future as deemed necessary.

3 Power Conversion Paths

Based on the type of mechanical motion, various PCCs are possible as shown in Fig. 3. On the left side of Fig. 3 is an overview of the stages of the chain, from the mechanical energy of the WEC, to the power transimssion, followed by the electrical generation and the power conditioning. Other optional components of the PCC were omitted in the figure for clarity, such as energy storage (batteries, etc) and mechanical or electrical rectification.

3.1 Technological Readiness

Some technologies involved in the PCC are currently used commercially, while other technologies still have major technical challenges to surmount before becoming a proven technology corresponding to TRL 9 [2], [3]. The technological readiness categorization shown in Fig. 3 is based on the work in the DNV Recommended Practices, found in [4], which takes into consideration the degree of the novelty of the technology as well as the application area. The matrix that DNV created to describe the dependency of these two variables on the technological readiness of a device is recreated in Fig. 4. A proven technology that is used in a known application area has no new technical technical uncertainties (i.e., it is considered a proven technology). On the other end of the spectrum, an unproven technology being applied to a new area is essentially a novel concept. There is much overlap between the categorizations defined by DNV and the TRLs that have been defined for marine hydrokinetic devices [2] and more specifically, wave energy devices [3]. Figure 3.1 shows how the green color in the DNV scheme corresponds to TRL 9 (proven technology), while the red color corresponds to TRL 1 (novel concept).

For instance, even though hydraulic pistons and motors are a proven technology, their application in a marine power conversion environment has relatively limited knowledge. In fact, since there have only been a few commercial or pre-commercial deployments of WECs in the world, nearly all technologies directly related to commercial wave energy conversion have 'limited knowledge'. Specifically, the application of drivetrain technology to WECs, where the technology is subject to the harsh and chaotic marine environment is certainly a field with technical uncertainties and challenges. Moreover, the bidirectional low-speed, high-torque behavior of many WEC devices presents further challenges to wave energy developers. Further downstream in the power conversion chain process, though, the wind industry has been applying rotary generators to a variable speed drivetrain for decades. Thus, this technology is deemed to be proven and the application area is known.

4 Power Transmission

4.1 Mechanical Drivetrain

A mechanical drivetrain is a mechanism that transmits power from the energy conversion mechanism to the rotor of the generator using mechanical elements, such as those found in a gearbox. For instance, as a wave passes over an oscillating wave-surge converter (like the Oyster device, labeled 'OWSC' in Fig. 2), the joint connecting the flap to the stationary platform experiences relative rotational motion. If the rotational speed is not adequate, it

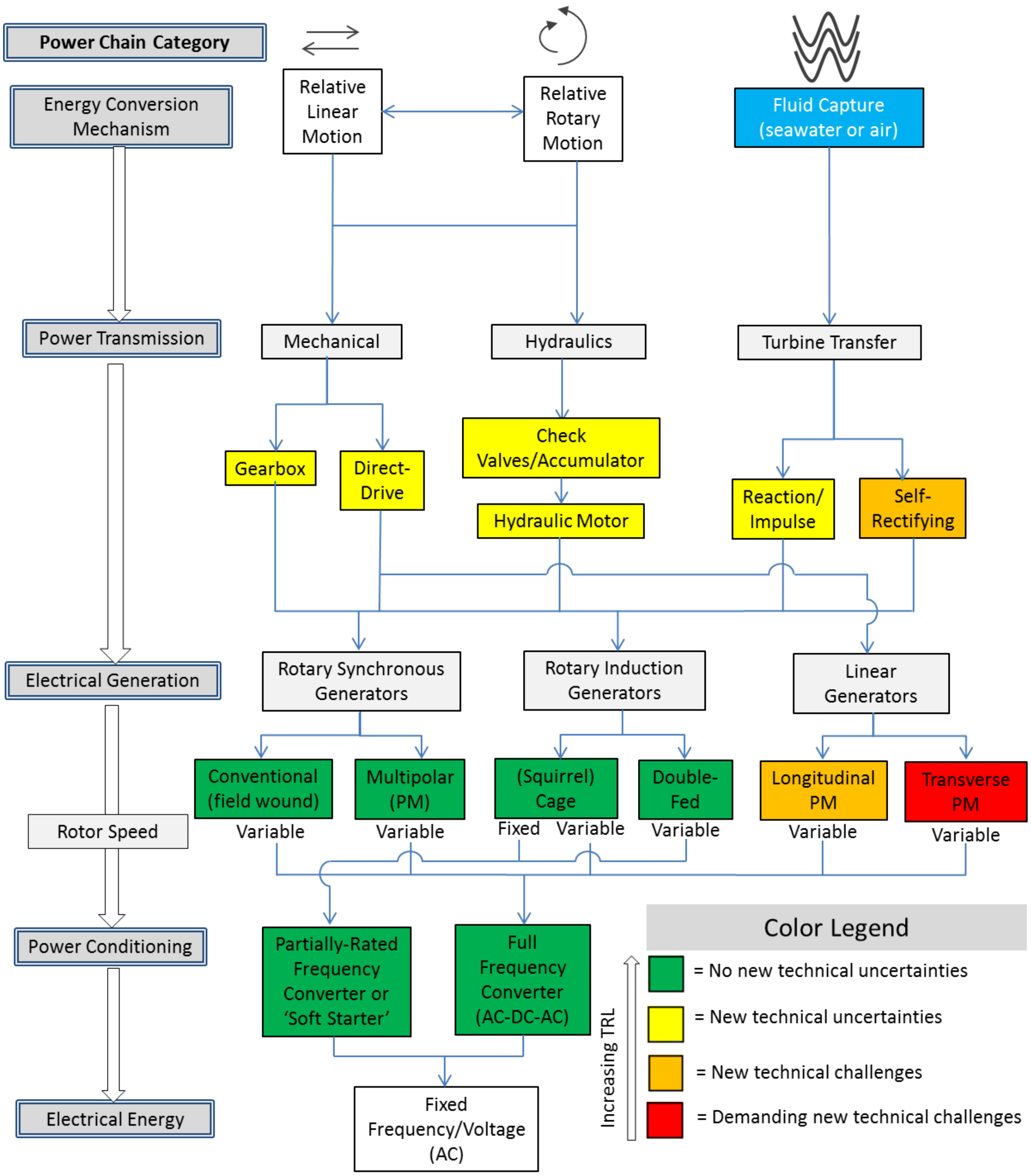

Figure 3: Power conversion chain from mechanical energy to electrical connection to grid. Blue arrows indicate possible power flow paths. The thick arrows and text boxes on the left side of the figure indicate each step of the power conversion chain process. Light grey colors indicate a grouping of technology while colors refer to technological readiness categorization, as defined in 'Color Legend' (see description of Fig. 4 for further explanation).

can be increased using a gearbox. The knowledge and experience surrounding mechanical drivetrains largely comes from the advances in the wind energy industry. There is a large

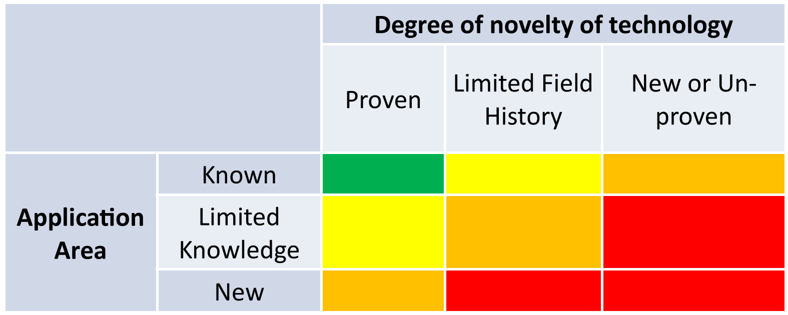

Figure 4: Technology readiness chart that takes into account the degree of novelty of the technology as well as the application area. For definitions of colors, see 'Color Legend' in Fig. 3. The application of a technology to a wave energy device is considered an area with limited knowledge, from [4].

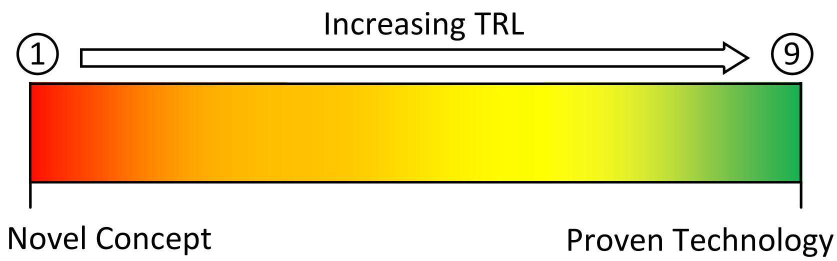

Figure 5: Comparison of DNV techonology categorization, shown in Figs. 3 and 4 and documented in [4], with TRL categorization, documented in [2] and [3].

overlap among wind turbines and wave energy converters since both are large-scale, grid-connected devices that convert a high-torque, low-rpm load into 50 or 60 Hz AC. However, caution should be taken before blindly applying wind turbine technology to the wave energy sector. The harsh marine environment should receive special attention. In Fig. 3 the drivetrain technology in wave energy converters is considered to have technical uncertainties because the mechanisms in the nacelle of a wind turbine have never been subjected directly to the marine environment (they only have been deployed on the ocean in the nacelles of offshore wind turbines, which are over 50 m above the ocean surface) or bidirectional rotational motion. In this study these transmission systems are separated into two categories: those with gearboxes and those without (i.e., direct-drive). Though the drivetrains without gearboxes are simpler machines, their use is not as widespread. The low-speed (10-25 rpm) high-torque generators that must be used for direct-drive applications are large, heavy and expensive. The size of the generators can be seen in Fig. 6, where the stator and rotor of the generator are the largest components in the nacelle. The first wind turbines and many of the subsequent designs use gearboxes to increase the rotational speed of the main axle (low-speed shaft) before connection to the generator (high-speed shaft). The angular displacement of the shaft attached to the WEC, itself, is denoted by θ_{LSS}, while the angular displacement of the shaft attached to the rotor of generator is denoted by θ_{HSS}. The gearbox, which connects

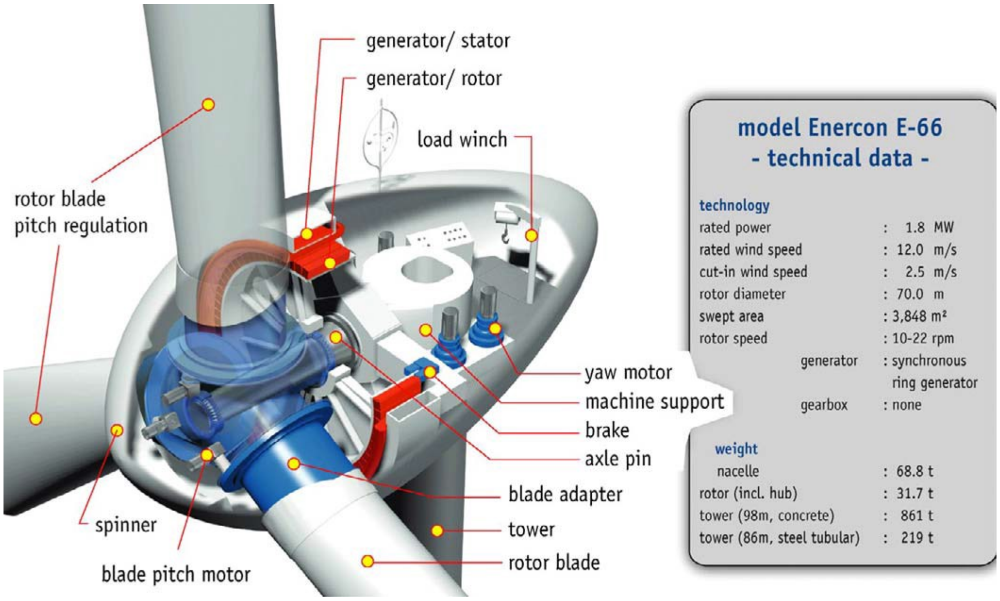

Figure 6: Cutaway diagram of an Enercon E-66 nacelle. This direct-drive transmission has a large synchronous permanent magnet generator, from [5].

these two shafts, can be modeled as a simple spring-damper system, as in [6] and shown in Eqs. 1 and 2,

$$T_{gb} = K_{gb}(\theta_{HSS} - \theta_{LSS}) + B_{gb}(\dot{\theta}_{HSS} - \dot{\theta}_{LSS}) \tag{1}$$

$$\theta_{HSS} = r_{gb}\theta_{LSS} \tag{2}$$

where T_{gb} is the torque on the WEC from the gearbox and r_{gb} is the gear ratio of the gearbox, which is greater than unity or equal to unity for a direct-drive system.

The NEG Micon 52, shown in Fig. 7, was one of the most common wind turbines in the 1990s and used a mechanical transmission with a gearbox. However, gearboxes are prone to failure and have high operation and maintenance costs. This issue could prove to be critical if these PCC were installed in a marine environment because maintenance operations are more costly and weather windows determine the maintenance frequency and duration on the ocean. There is currently very little public information about the use of these types of transmissions as applied to wave energy converters. However, a model for a gearbox is included in FAST and can be modified for use in the drivetrain portion of the PTO-Sim module. Historically, wave energy developers have implemented hydraulic PCCs rather than mechanical drivetrain transmissions (see Sec. 6 for a survey of PCCs used by wave energy developers), however more recently developers (such as Ocean Power Technologies and Columbia Power Technologies) are turning towards direct-drive systems.

4.2 Hydraulic Drivetrain

The most popular drivetrain used in pre-commercial or commercial wave energy devices (TRL5+) utilizes hydraulic fluid and a hydraulic motor. The relative rotational or linear

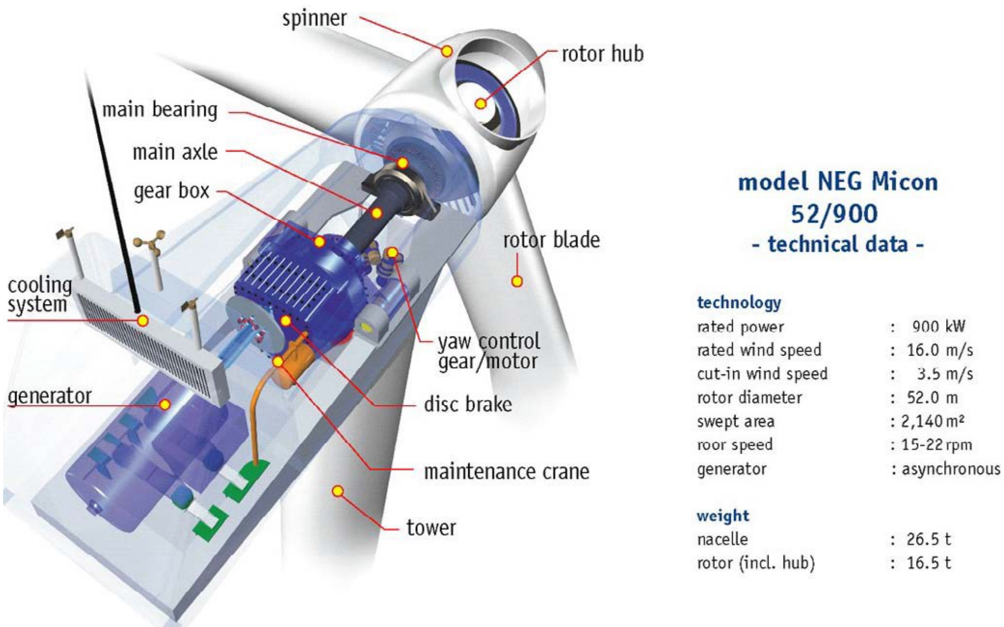

Figure 7: Cutaway diagram of an NEG Micon 52 nacelle. This nacelle has a gearbox and smaller electrical generator compared to the Enercon E-66, from [5].

motion drives a hydraulic cylinder, which pumps fluid into an accumulator. Once enough pressure has built up in the accumulator, the high-pressure fluid drives a hydraulic motor. The motor is connected to a rotary generator, which produces electricity and provides a resistive torque on the motor. The most detailed hydraulic drivetrain built and tested was the one installed on the Ocean Power Delivery's Pelamis Device. A modified schematic of the Pelamis system is shown in Fig. 8. If we assume the hydraulic fluid is incompressible, then the volumetric flow out of the cylinder, $\dot{V}_{cyl}$ is related to the relative linear velocity of the hydraulic cylinder, $\dot{x}$, by Eq. 3. The control manifold allows fluid to travel from the cylinder into the high-pressure lines, so that all fluid exiting the cylinder enters the high-pressure accumulator (shown by the last equality in Eq. 3).

$$\dot{V}_{cyl} = \dot{x} A_{cyl} = \dot{V}_{HP,in} \tag{3}$$

The accumulators are initially filled with nitrogen gas. The time rate of change of the volume of fluid in the accumulators $\dot{V}_{HP,f}$, or $\dot{V}_{LP,f}$ is equal to the flow rate coming into the accumulator plus or minus the flow rate entering or leaving the hydraulic motor, as shown by the first equalities in Eqs. 4 and 5. Since the total volumes of each accumulator are fixed, the volume of nitrogen in each accumulator, $V_{HP,Ni}$ and $V_{LP,Ni}$, will decrease as the accumulators fill up with hydraulic fluid (last equality in Eqs. 4 and 5).

$$\dot{V}_{HP,f} = \dot{V}_{HP,in} - \dot{V}_m = -\frac{dV_{HP,Ni}}{dt} \tag{4}$$

$$\dot{V}_{LP,f} = -\dot{V}_{LP,in} + \dot{V}_m = -\frac{dV_{LP,Ni}}{dt} \tag{5}$$

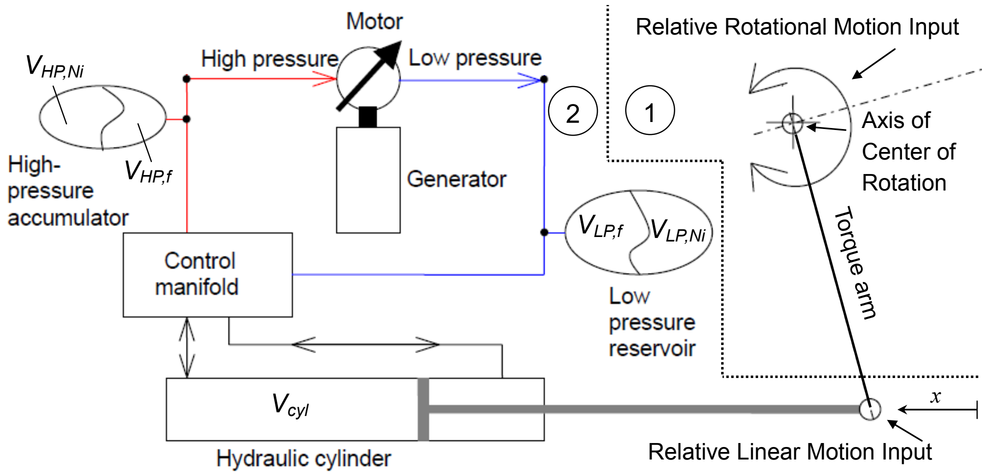

Figure 8: Simplified schematic of a hydraulic system, including cylinders, accumulator, motor and electric generator, adapted from [7]. The system can either be driven from relative rotational motion (systems 1 and 2) or linear motion (system 2, alone).

We assume nitrogen is an ideal gas and the process to be isentropic. The pressures and volumes of the gas in each of the accumulators are known initial conditions. The dynamic pressures, $p_{HP}(t)$ and $p_{LP}(t)$, which are the pressures in the high-pressure and low-pressure accumulators, respectively are,

$$p_{HP}(t) = p_{HP,Ni}(0)\left(\frac{V_{HP,Ni}(0)}{V_{HP,Ni}(t)}\right)^{1.4} \tag{6}$$

$$p_{LP}(t) = p_{LP,Ni}(0)\left(\frac{V_{LP,Ni}(0)}{V_{LP,Ni}(t)}\right)^{1.4} \tag{7}$$

The force from the hydraulic system on the body, F_{PTO}, can be estimated as,

$$F_{PTO}(t) = -\left[p_{HP}(t) - p_{LP}(t)\right] A_{cyl}\,\mathrm{sgn}\,\dot{x}(t) \tag{8}$$

The main advantage of using a hydraulic system is the ease of storing energy in the high-pressure accumulator. One of the most difficult challenges of capturing wave energy is the variability of the instantaneously absorbed power. The instantaneous power incident on the device can be nearly four times the mean absorbed power on the device (the purple curve in Fig. 9). However, the power delivered to the generator should be relatively constant or else the power quality can suffer and damage can occur to the generator and power electronics. Figure 9 shows how the power generated by the motor in the Pelamis device remains nearly constant around 200 kW. One of the disadvantages of using hydraulics is the risk of leaking working fluid into the marine environment (see [8] for more information). The Pelamis WEC, however, uses biodegradable transformer fluid as well as extensive protection against the influx of seawater into the hydraulic system [7].

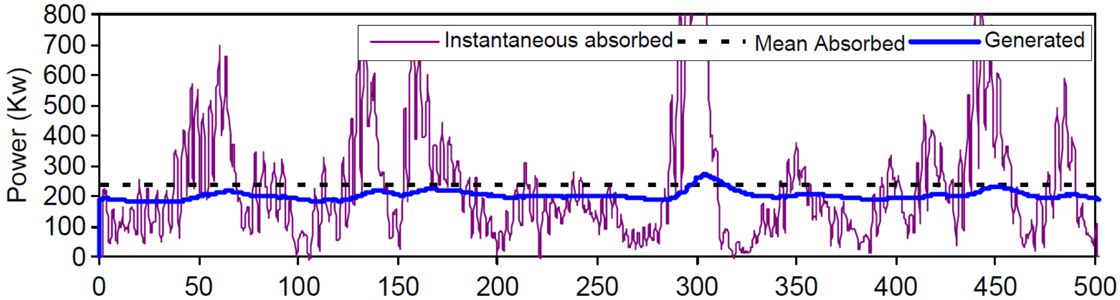

Figure 9: Time history of instantaneous power absorbed by Pelamis device (purple curve) as well as the power generated by electrical generator (blue curve), from [7].

4.3 Turbine Transfer

A wave energy converter can also capture energy from an incident wave without exhibiting any relative linear or rotary motion between members. In this transmission concept, known as turbine transfer, seawater or air is forced through an orifice, driving a turbine. In most oscillating water columns, a self-rectifying turbine (most commonly the Wells turbine) is used to capture the energy in the reciprocating airflow, as shown in Fig. 10. A self-rectifying turbine rotates in the same direction regardless of the direction of the inflow of fluid. However, the Wells turbine suffers from relatively low efficiency, only about 60-65% [9]. In overtopping devices, or in devices where the fluid flow is mechanically rectified (such

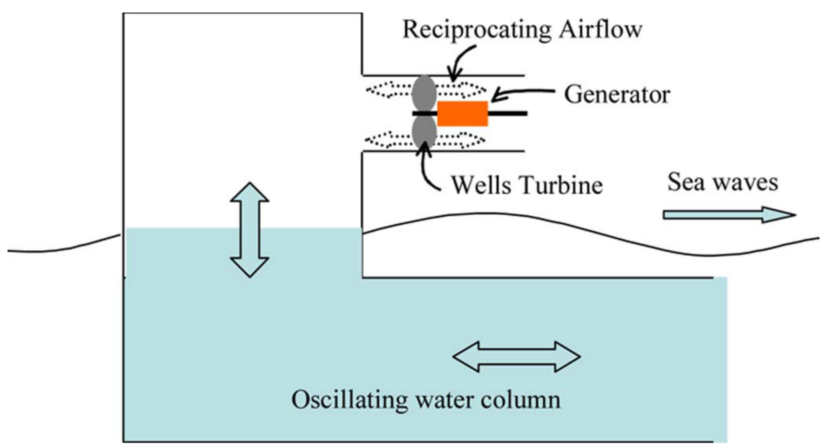

Figure 10: Schematic of backward bent duct buoy, a type of oscillating water column, utilizing a Wells turbine to capture the energy from reciprocating airflow, from [10].

as through check valves) a reaction or impulse turbine can be used instead, as shown in Fig. 11. For the Wave Dragon, which is an overtopping device, a low-head hydroelectric turbine can be used. The authors in [11] caution that the since the turbines must operate at a wide range of head values in the hostile marine environment, special care should be taken in the modification of a normal low-head hydroelectric turbine. A thorough comparison of various Wells turbines and impulse turbines with pitch-controlled vanes is performed in [12].

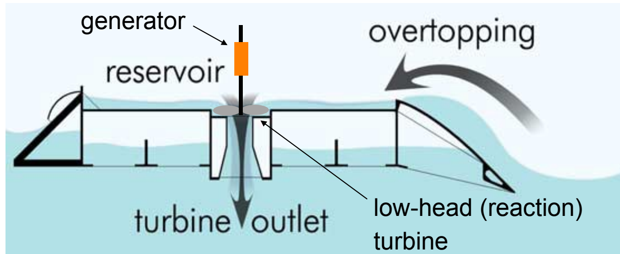

Figure 11: Schematic of Wave Dragon, an overtopping device, utilizing a low-head turbine to capture the potential energy from the incident wave, adapted from [11].

Kim et al show that the impulse turbine with self-pitch-controlled guide vanes is the superior turbine over a wide range of wave frequencies.

5 Electrical Generation and Power Conditioning

5.1 Types of Electric Generators Suitable for WECs

In the power conversion chain, the actual generation of electricity is the most crucial step. Electric generators that produce alternating current can be divided into two groups: induction (asynchronous) machines and synchronous machines. A *synchronous* generator produces a voltage with a waveform that is synchronized with the rotation of the rotor. The synchronous speed, ω_s (in rpm) can be determined by the number of the poles of the stator, P, and the frequency of the network voltage, f (60 Hz, in North America).

$$\omega_s = 120\frac{f}{P} \tag{9}$$

An *asynchronous* generator operates at a speed that is slightly faster than the synchronous speed. The difference between these two speeds, known as the slip speed, can vary slightly without decreasing the performance of the generator. Due to the inherent variability of the wind, many early wind technology developers opted to use asynchronous generators. Hence, the slip range of the generator was used to provide a small buffer for changes in the rotational speed of the rotor. In the past couple of decades, however, advances in the power electronics field have enabled fully variable-speed generators to be installed in wind turbines, both synchronous and induction types [10]. In the induction generators the power electronics can control the rotor voltage and frequency, while the stator voltage and frequency is controlled in synchronous generators.

5.2 Induction Generators

5.2.1 Fixed-Speed Induction Generators

There are two main types of induction generators used in the wind energy industry, the doubly-fed induction generator (DFIG) and the squirrel cage induction generator (SCIG).

The SCIG represented the most common generator used until around 1998. These generators, shown in Fig. 12, were mostly fixed-speed turbines with a three-stage gearbox and power levels below 1.5 MW [5]. This type of generator has little applicability to the wave energy

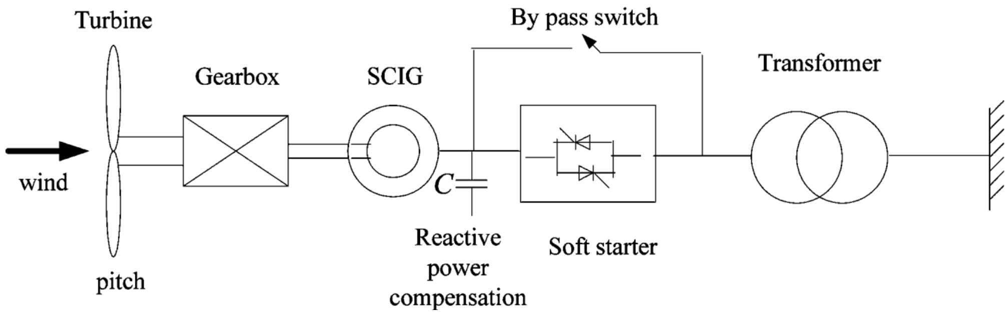

Figure 12: Schematic of fixed-speed squirrel cage induction generator, with power electronic soft-starter, from [13]. The 'ground' on the right side of the figure represents the connection with the grid.

industry because it runs at a relatively fixed speed. The only devices that would incorporate such a generator would be one that utilizes a hydraulic drivetrain. Since the accumulators can smooth the instantaneous power, the hydraulic motor can run at a near constant speed.

5.2.2 Variable-Speed Induction Generators

From 1996-2000, most wind turbine manufactures switched to the doubly fed induction generator (DFIG), due to the desire to have a variable speed rotor. This generator, shown in Fig. 13 with a control scheme, enabled the rotor to vary within a range of $\pm 30\%$ of the nominal speed. These turbines were usually rated for 1.5 MW and exhibited reduced audible noise while increasing their ability to handle dynamic loads. These drivetrains had to include a partially rated power electronic converter (approximately 25% of the full rated power of the turbine) as well as brushes [5]. The addition of brushes increases the maintenance requirement for the power conversion chain because they wear out and must be replaced after a certain number of cycles. The most complicated generator modeled in FAST is a Thevenin-equivalent, 3-phase variable-speed induction generator. The torque applied to the drivetrain is a function of the architecture of the generator, including the number of poles, the resistances and magnetic leakage of the stator and rotor [6].

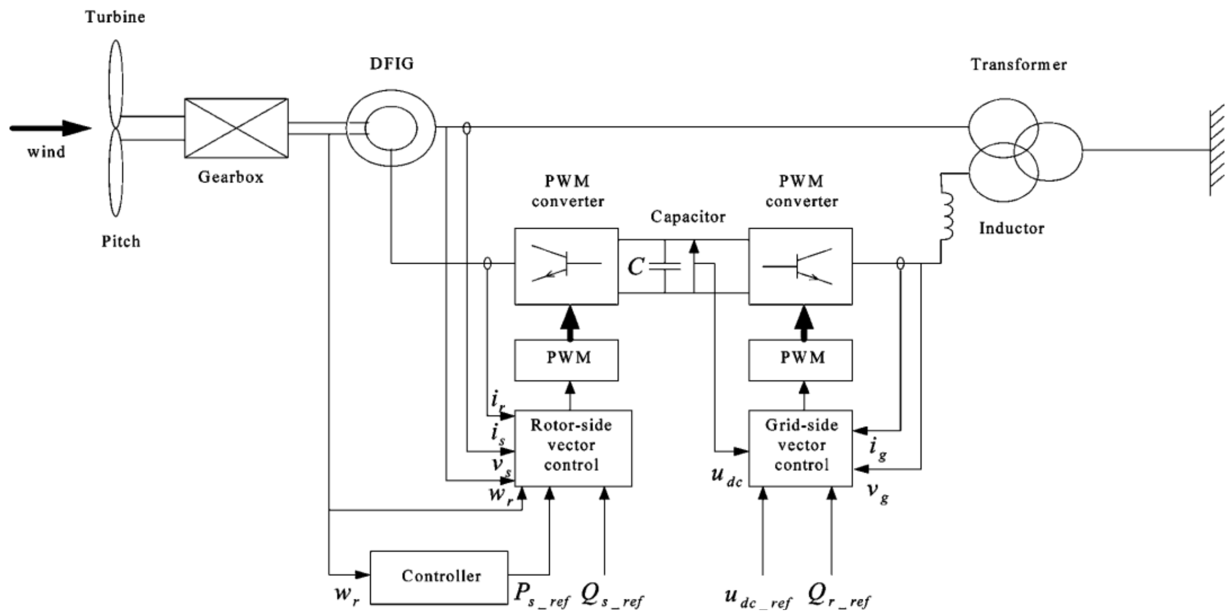

Figure 13: Schematic of variable-speed doubly fed induction generator, with power electronic soft-starter, from [13].

5.3 Variable-Speed Synchronous Generators

The most basic type of synchronous generator is a field wound generator. A schematic of this generator with a full frequency converter is shown in Fig. 14. A full frequency converter converts the three-phase AC to DC, where some of the electric energy is momentarily stored in a capacitor bank, and then back to AC before it is sent to the transformer and the grid. A direct-drive synchronous generator was shown in Fig. 6, in the nacelle of the

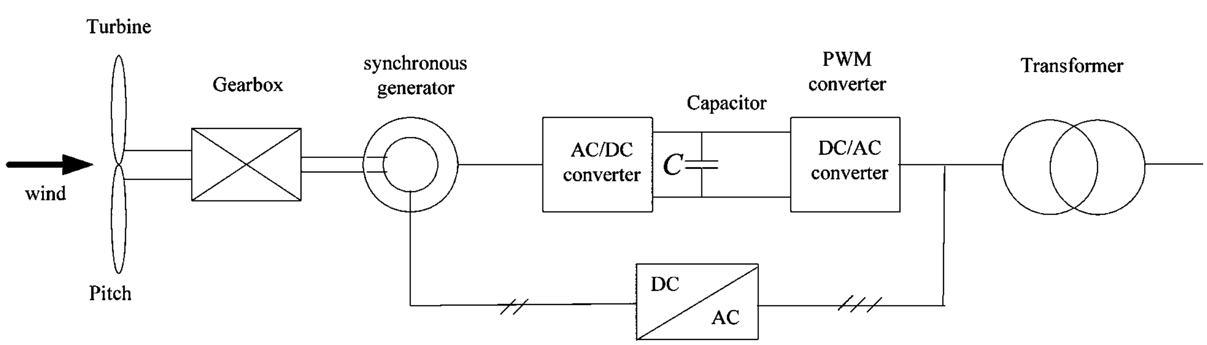

Figure 14: Schematic of variable-speed wound synchronous generator, with full power electronics converter, from [13].

Enercon E-66. This synchronous generator includes permanent magnets, which provide the excitation field. The schematic of this type of generator is shown in Fig. 15. Although full

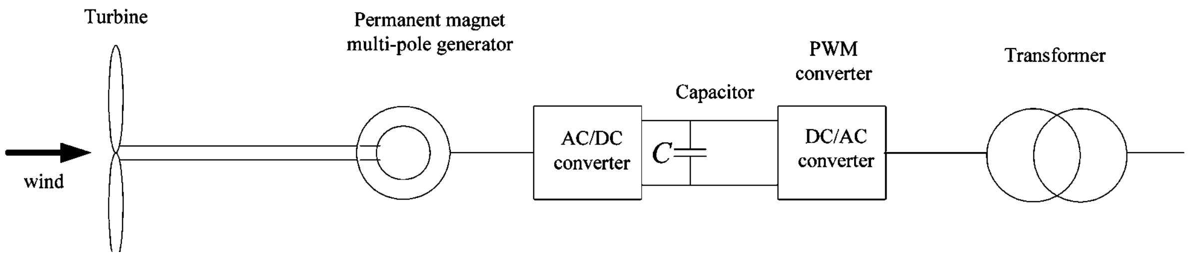

Figure 15: Schematic of direct-drive variable-speed permanent synchronous generator, with full power electronics converter, from [13].

rated power electronics are costly and heavy, the generator can operate at a wide range of frequencies because it is decoupled from the grid. The wind turbines exhibit better performance when their rotational speed can be controlled dynamically [13]. This is certainly true for wave energy converters as well, which should be tuned to the predominant sea state. Historically, the cost of permanent magnets and rare earth materials have been prohibitively high. However, in recent years the cost of these materials has been dropping, making these types of generators more attractive.

5.4 Linear Generators

The simplest type of wave energy converter exhibits relative linear motion. A buoy bobs up and down on the wave, while a deeply submerged (or bottom mounted) mass has relatively little motion, as shown in Fig. 16. Many wave energy developers have tried to directly connect this motion with a generator. However, linear generators do not have the same kind of field history as rotary generators. There are two types of linear generators depending on the plane in which the magnetic flux travels. In longitudinal flux generators, the flux flows parallel to the direction of the motion of the rotor. This type of linear generator is shown in Fig. 16. The part labeled 'piston' in Fig. 16 represents a stack of permanent magnets. The stators, which are located on two sides of the rotor include electrically-conducting wire. Thus, a current is induced in the wires as the magnetic field changes with the motion of the piston. In transverse flux generators, the flux flows around the rotor, that is, in a plane that is oriented normal to the axis of motion of the rotor. Although numerical work by [14] has shown that transverse flux machines may be more suitable for wave energy applications than their longitudinal brethren, the authors also state that a significant supporting structure is necessary to overcome the large radial forces produced by the permanent magnets oriented in this manner.

6 Survey of Existing PCCs

In order to determine which components of the PCC should be modeled in the WEC-Sim project, we must consider their current popularity among WEC developers. The Energy Efficiency and Renewable Energy Program has a Marine and Hydrokinetic Technology Database

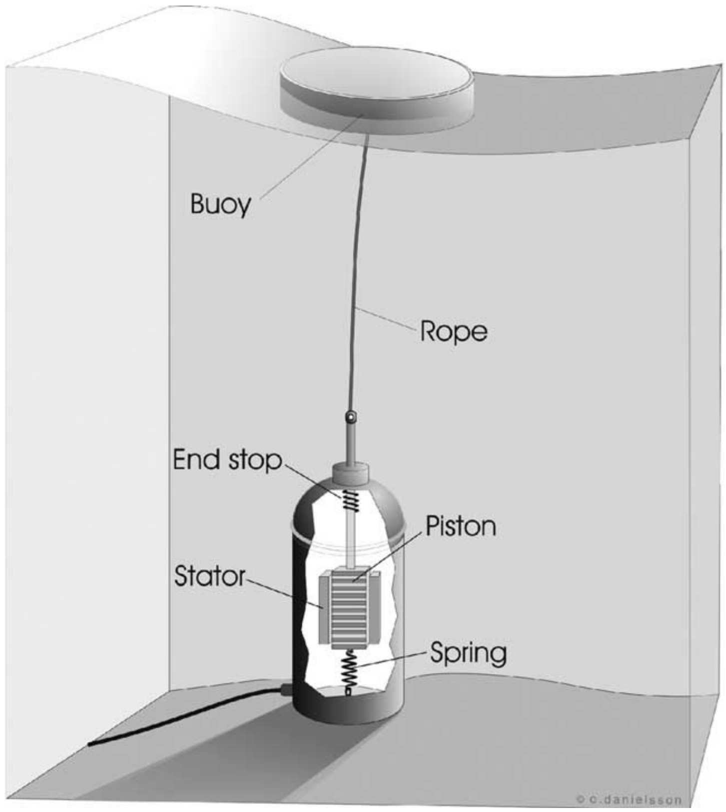

Figure 16: Schematic of direct-drive point absorber with a linear generator, from [15].

[16], where developers can enter information about their device and its technological readiness level (TRL). By filtering out devices with TRL less than 5, we can survey the technologies that have been tested at full-scale or with near full-scale prototypes. The results of this survey are shown in Fig. 17. Just under half of all the large-scale models and full-scale prototypes use a hydraulic drivetrain. Thus, the PTO-Sim module would be incomplete without including a hydraulic library. Around 50% of the devices that do not use a mechanical drivetrain did not specify whether their device was connected directly to a generator or not. While the need for intellectual property is understandable, withholding even high-level information inhibits projects such as this one, whose benefit to industry would be enhanced with more information. Devices that capture fluid represent around 20% of the total number of WECs surveyed. The modeling of these devices is substantially different than other WECs because they involve detailed analysis of the fluid dynamics of the working fluid as well as the fluid-structure interaction between the air or seawater and the turbine blades.

7 Recommendations and Code Development

One of the main challenges in the PTO-Sim project is to determine exactly what parts of the power conversion chain to model and at what levels of fidelity. For instance, the modeling of the power conditioning systems may not be necessary for this project, where the main

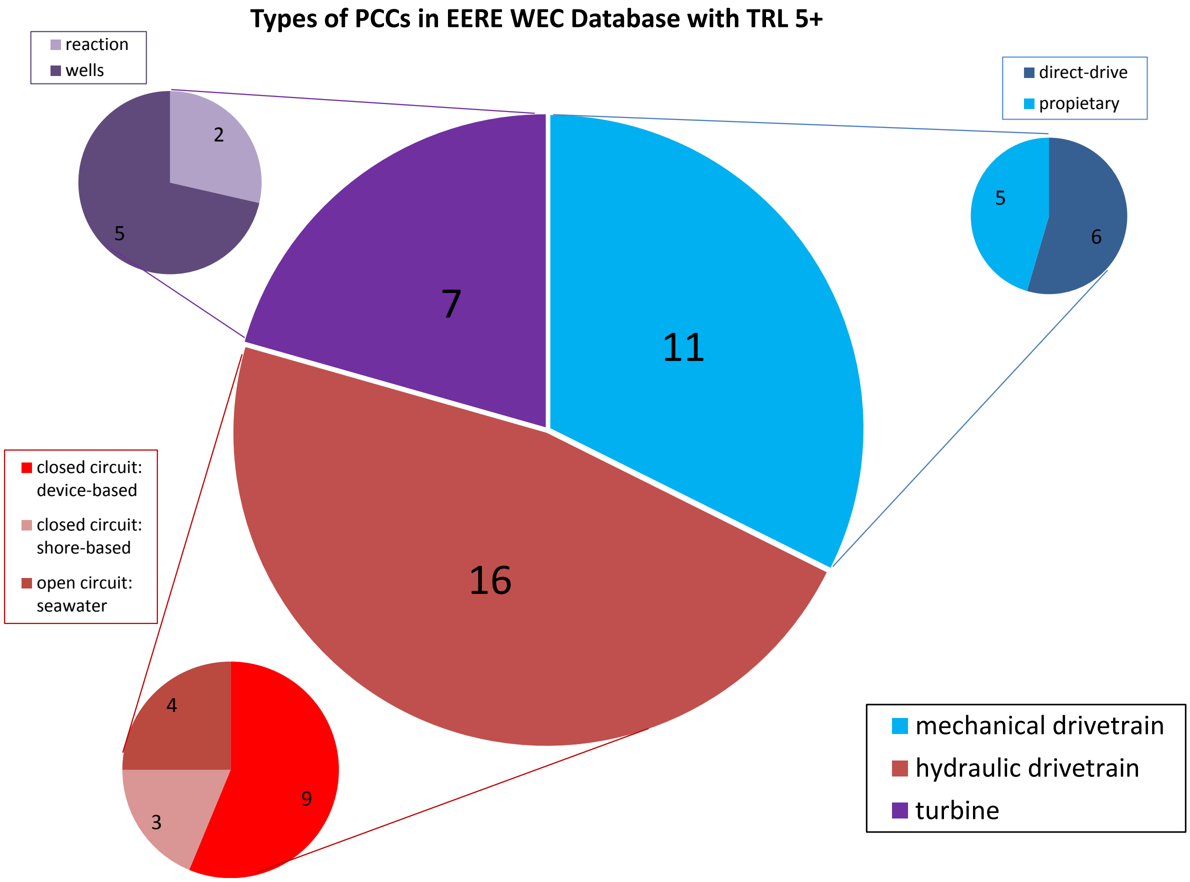

Figure 17: Breakdown of PCC types currently used by companies with technological readiness level equal to or greater than 5.

focus is the dynamics of the device. The quality of the electric power produced is not included in the scope of this project. Regardless of which steps on the power conversion chain are included in this model, the most important aspect of the project should be to estimate the power at each step of the process. Thus, the efficiency of the device, transmission, generator, etc, can each be evaluated individually.

At its most basic level, a simple spring and damper system can be used to represent the power absorbed by a generator. This assumption has been made by many wave energy developers, especially when trying to come up with an optimal control scheme. For the model to be realistic, the PTO-Sim model must include the capability of controlling the drivetrain or the generator or both. However, we must assume that WEC developers have prior knowledge of control schemes and can implement an appropriate one for their specific device. Since the PTO-Sim module will be written in the SIMULINK language, the addition of a control scheme will be relatively seamless. We believe it is currently out of the scope of this project to develop optimal control schemes for the PTO-Sim module, however this is a possible future topic.

Due to the popularity of hydraulic drivetrains among current WEC developers a hydraulic module will be included in PTO-Sim. This model builds on work performed by the second author at Oregon State, detailed in [17]. This model will be relatively straightforward to incorporate into the WEC-Sim project because it is already coded in MATLAB/SIMULINK. The mechanical drivetrain, either a gearbox or a direct-drive mechanism should be modeled, with the gearbox in FAST used as a reference. The Thevenin-equivalent induction generator, modeled in FAST can be incorporated in the WEC-Sim project in order to obtain a more realistic estimate of the applied torque from the generator. We believe that devices that capture fluid as a power conversion mechanism are out of the scope of the first iteration of this project due to the complexity of modeling the fluid and the fluid-structure interaction.

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