

# Wave-to-wire modelling: An application-sensitive approach

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## Abstract

Wave-to-wire (W2W) models are valuable tools for a variety of applications in the development of wave energy converters (WEC). However, computational and fidelity requirements of each application can be very different. Therefore, this study suggests an application-sensitive *systematic* complexity reduction approach that reduces computational requirements, while retaining a level of fidelity that is relevant for each application. Such reduced W2W models can achieve high fidelity values similar computational requirements shown by the traditionally used linear mathematical models.

## Introduction

The different subsystems involved in energy generation from ocean waves to the electricity grid, including wave-structure hydrodynamic interactions (WSHIs) and hydraulic power take-off (HyPTO) systems, are illustrated in Figure 1. Different dynamics, losses and nonlinear effects in different subsystems may be important depending on the application for which the numerical model is designed.

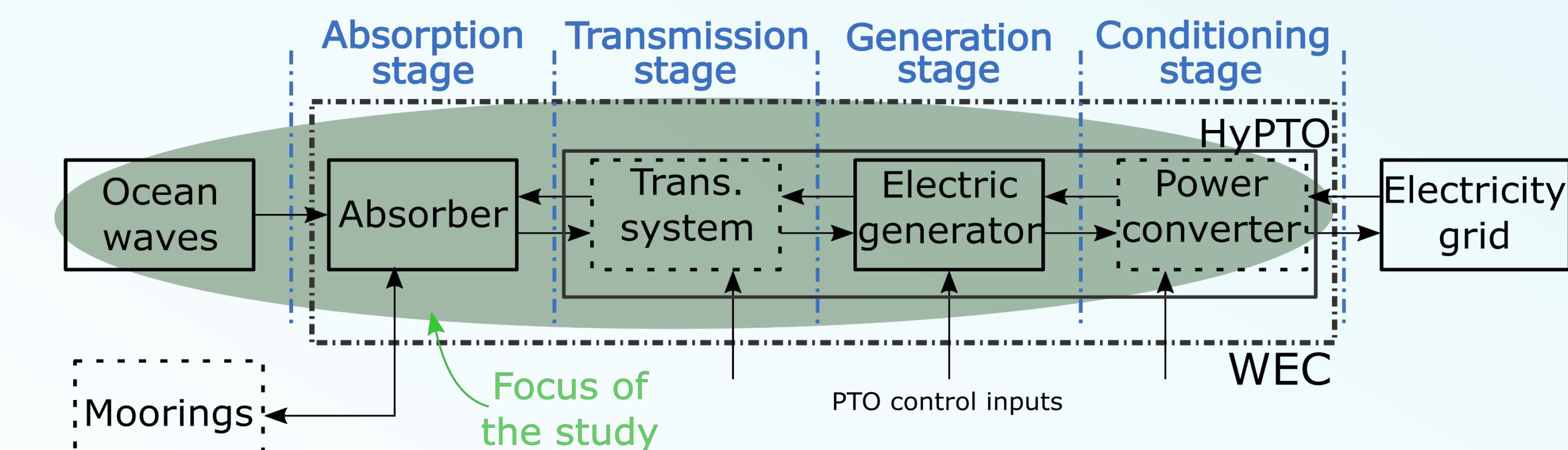


Figure 1: Schematic representation of the subsystems involved in wave energy generation.

Potential applications of W2W models and their specific requirements are listed in Table 1, showing that relatively high-fidelity is important in almost all applications, while high computational cost is acceptable only in a few of them.

Potential applications	Accuracy & Computational cost		Specific dynamics & losses					Nonlinear effects
	$F_{gen}$ fidelity	Low computational cost	WSHI*	Hydraulic system dynamics	Hydraulic systems losses	Electrical dynamics	Electric generator losses	
Validation & verification (VerVal)	+++	---	✓	✓	✓	✓	✓	×
Identification (Ident)	+++	---	✓	✓	✓	✓	✓	✓
WEC simulation (SimWEC)	++	-	✓	✓	✓	✓	✓	×
Power system (PowSys)	++	-	×	✓	✓	✓	✓	×
Model-based control (MBC)	++	+++	×	×	✓	×	✓	✓
Power assessment (PowAss)	++	++	×	×	✓	×	✓	×
PTO optimisation (PTOopt)	++	++	×	✓	✓	×	✓	×

Table 1: Specific requirements of the potential applications that demand W2W models.

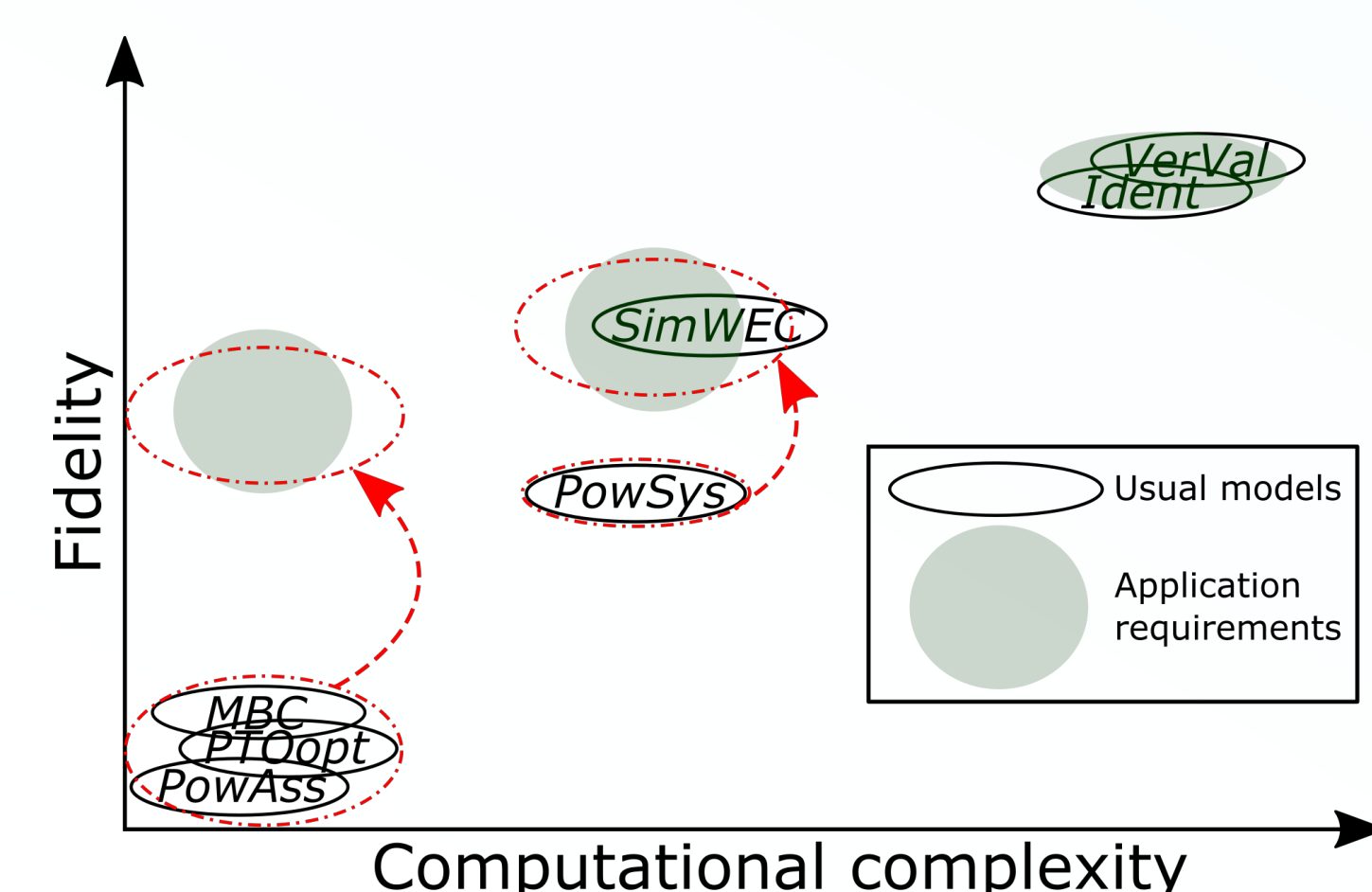


Figure 2: Fidelity/complexity trade-off for common applications.

The fidelity/complexity compromise of different applications and commonly used numerical models for those applications, are illustrated in Figure 2, showing significant discrepancy in applications for which low computational requirements are essential.

Therefore, an approach that reduces the computational requirement, while retaining a certain level of fidelity, is vital. To that end, a Systematic complexity reduction (CR) approach is suggested.

## Complexity reduction

The systematic CR approach consists of removing/linearising different dynamics/loss models from the different subsystems of the high-fidelity simulation platform *HiFiWEC*, which combines a CFD model with a complete HyPTO model [1]. Hence, reduced WSHI models (*rWSHI*) and reduced HyPTO models (*rHyPTO*) are designed, as illustrated in Figure 3.

*rWSHI* models are all based on potential flow (PF) theory, using linear (Lin) and nonlinear (NL) representation of different forces.

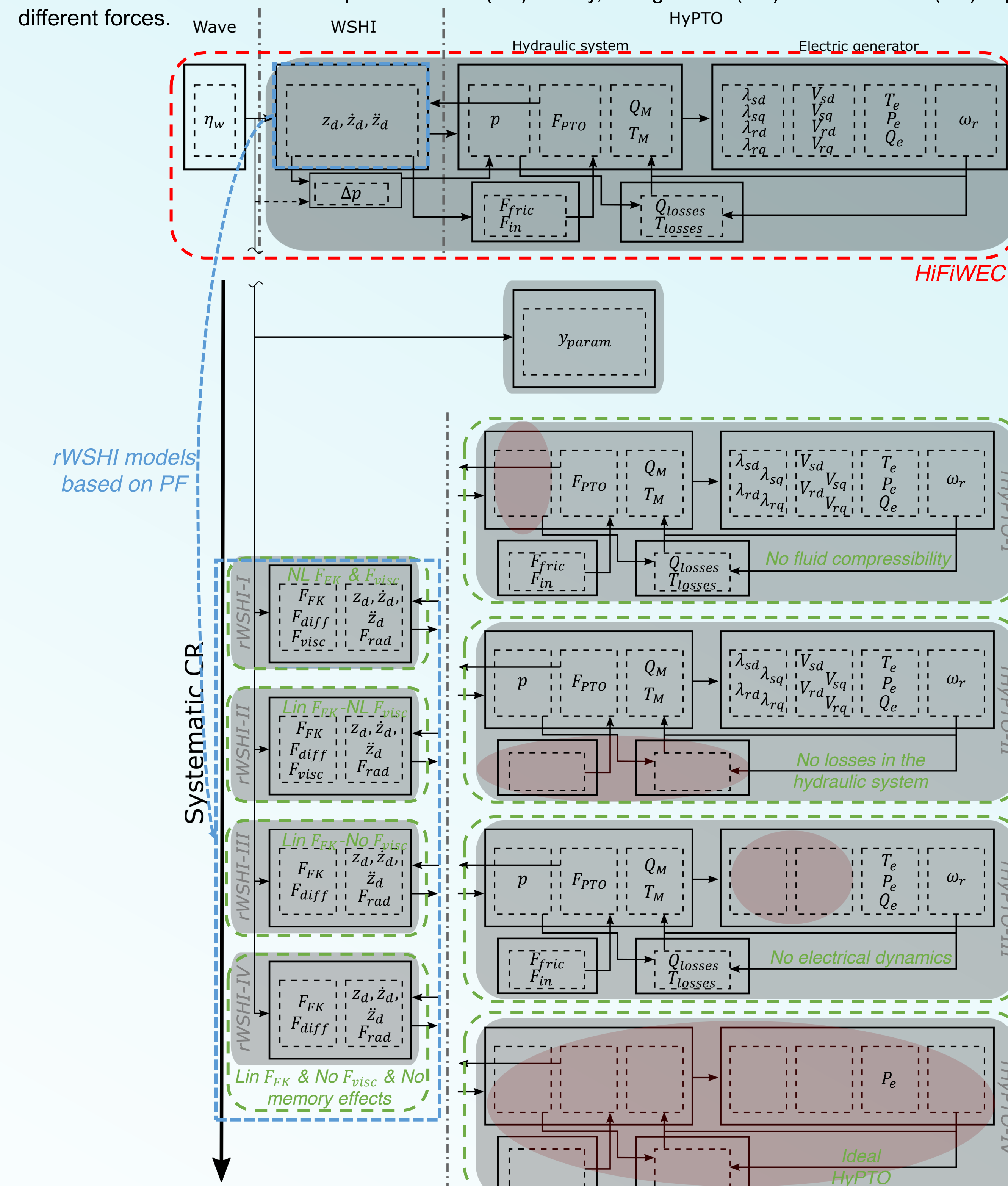


Figure 3: Schematic illustration of the *HiFiWEC* and the different *rWSHI* and *rHyPTO* models.

Balanced <i>rHyW2W</i>	WSHI	HyPTO
<i>rHyW2W-I</i>	<i>rWSHI-I</i>	<i>cHyPTO</i>
<i>rHyW2W-II</i>	<i>rWSHI-III</i>	<i>cHyPTO</i>
<i>rHyW2W-III</i>	<i>rWSHI-I</i>	<i>rHyPTO-I</i>
<i>rHyW2W-IV</i>	<i>rWSHI-I</i>	<i>rHyPTO-II</i>
<i>rHyW2W-V</i>	<i>rWSHI-I</i>	<i>rHyPTO-III</i>
<i>rHyW2W-VI</i>	<i>rWSHI-I</i>	<i>rHyPTO-I &amp; -III</i>

Table 2: Configuration of the different balanced *rHyW2W* models.

Red circles in Figure 3 represent the dynamics/loss models that have been removed or linearised in each subsystem.

Hence, combining the different *rWSHI* and *rHyPTO* models, reduced W2W models (*rHyW2W*) that are reasonably balanced (from a complexity perspective) are created.

Table 2 lists the six balanced *rHyW2W* models compared in the present study.

## Reduced model selection

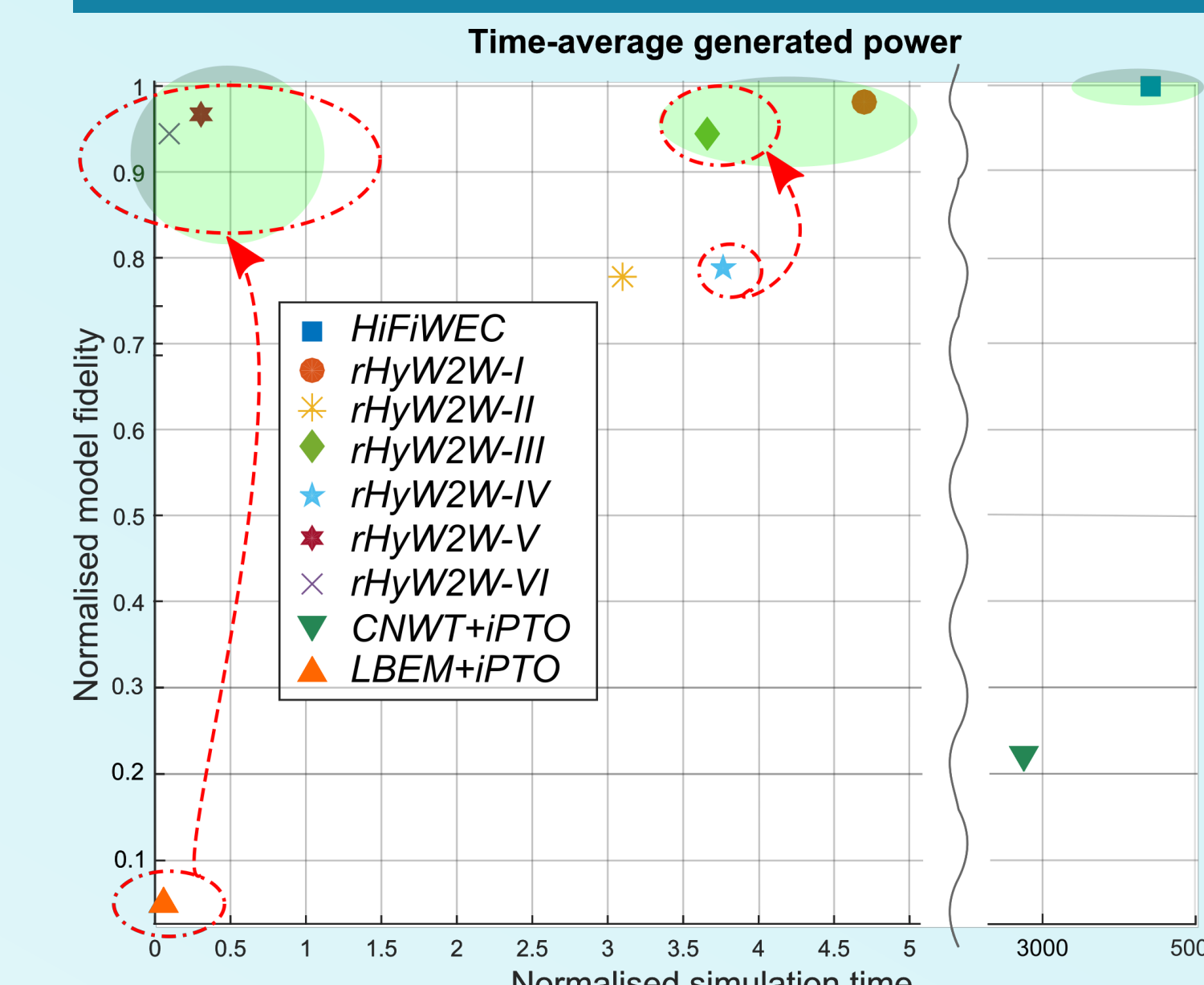


Figure 4: Fidelity/computational cost trade-off for different *rHyW2W* models.

Characteristics of the different *rHyW2W* models are shown in Table 3, using the following metrics:

- Fidelity ( $F$ ):** normalised, using the *HiFiWEC* as benchmark.
- Nonlinearity measure ( $\chi$ )** [2]: degree of nonlinearity.  $\chi = 0$  corresponds to a linear model, while  $\chi = 1$  means that the model is highly-nonlinear.

In addition, two unbalanced W2W models are included into the analysis:

- CNWT+iPTO:** WSHI modelled via CFD with an ideal HyPTO model
- LBEM+iPTO:** Linear WSHI model coupled to an ideal HyPTO model

Figure 4 illustrates the fidelity/computational cost trade-off of the different *rHyW2W* models, where computational cost is normalised against real time:

$$\tau_{ratio} = \frac{\text{simulation time}}{\text{real time}}$$

<i>rHyW2W</i> models	$\tau_{ratio}$	Resistive control		Reactive control	
		$F$	$\chi$	$F$	$\chi$
<i>rHyW2W-I</i>	4.7	0.95	0.23	0.97	0.12
<i>rHyW2W-II</i>	3.1	0.89	0.22	0.77	0.11
<i>rHyW2W-III</i>	3.7	0.94	0.15	0.94	0.09
<i>rHyW2W-IV</i>	3.8	0.51	0.21	0.79	0.11
<i>rHyW2W-V</i>	0.31	0.95	0.23	0.95	0.12
<i>rHyW2W-VI</i>	0.1	0.95	0.15	0.94	0.08

Table 3: Fidelity, computational cost and nonlinearity of the *rHyW2W* models.

Matching the characteristics of the *rHyW2W* models and application requirements, *specific HyW2W* models can be designed for each application:

Specific <i>HyW2W</i> model	VerVal	Ident	SimWEC	PowSys	MBC	PowAss	PTOopt
	<i>HiFiWEC</i>	<i>HiFiWEC</i>	<i>rHyW2W-I</i>	<i>rHyW2W-III</i>	<i>rHyW2W-V</i>	<i>rHyW2W-VI</i>	<i>rHyW2W-VI</i>

Table 4: The specific *HyW2W* model for each application.

## Conclusions

- Excessive simplification of the WSHI model, with all linear forces, can result in very poor results, particularly under control:
  - Nonlinear  $F_{FK} + F_{visc}$  provide significant improvement.
- Parsimonious representation of the HyPTO system is also crucial:
  - Only dynamics/losses that are vital to a particular application.
- Maximum fidelity can only be achieved with the *HiFiWEC*, but reasonably high-fidelity can be obtained for a fraction of the computational time.

## References

- Penalba, M., Davidson, J., Windt, C., & Ringwood, J. V. (2018). A high-fidelity wave-to-wire simulation platform for wave energy converters: Coupled numerical wave tank and power take-off models. *Applied Energy*, 226C, 655–669. <https://doi.org/10.1016/j.apenergy.2018.06.008>
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