SuperGen UK Centre for Marine Energy Research
Annual Assembly 2012

State-Space and System Identification Modelling of the Wave-to-Wire Response of Up-scaled Arrays

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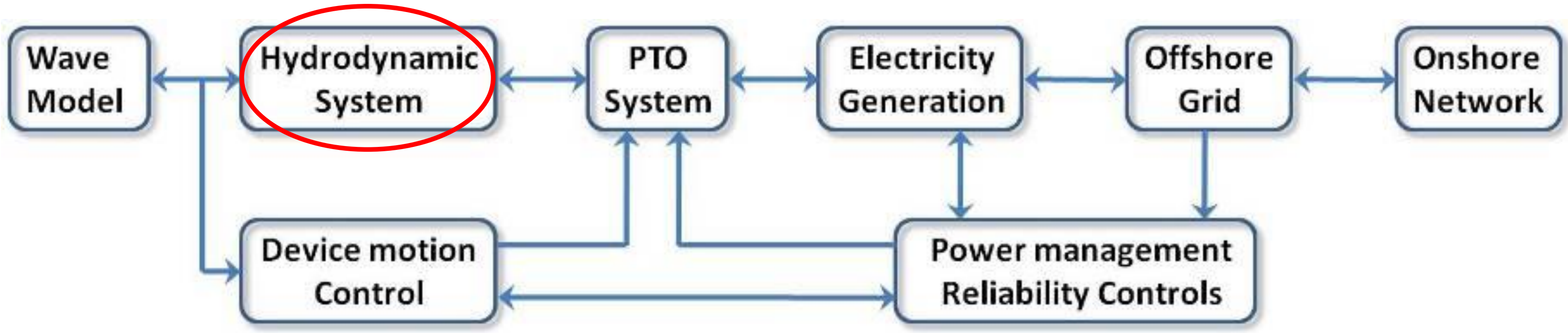
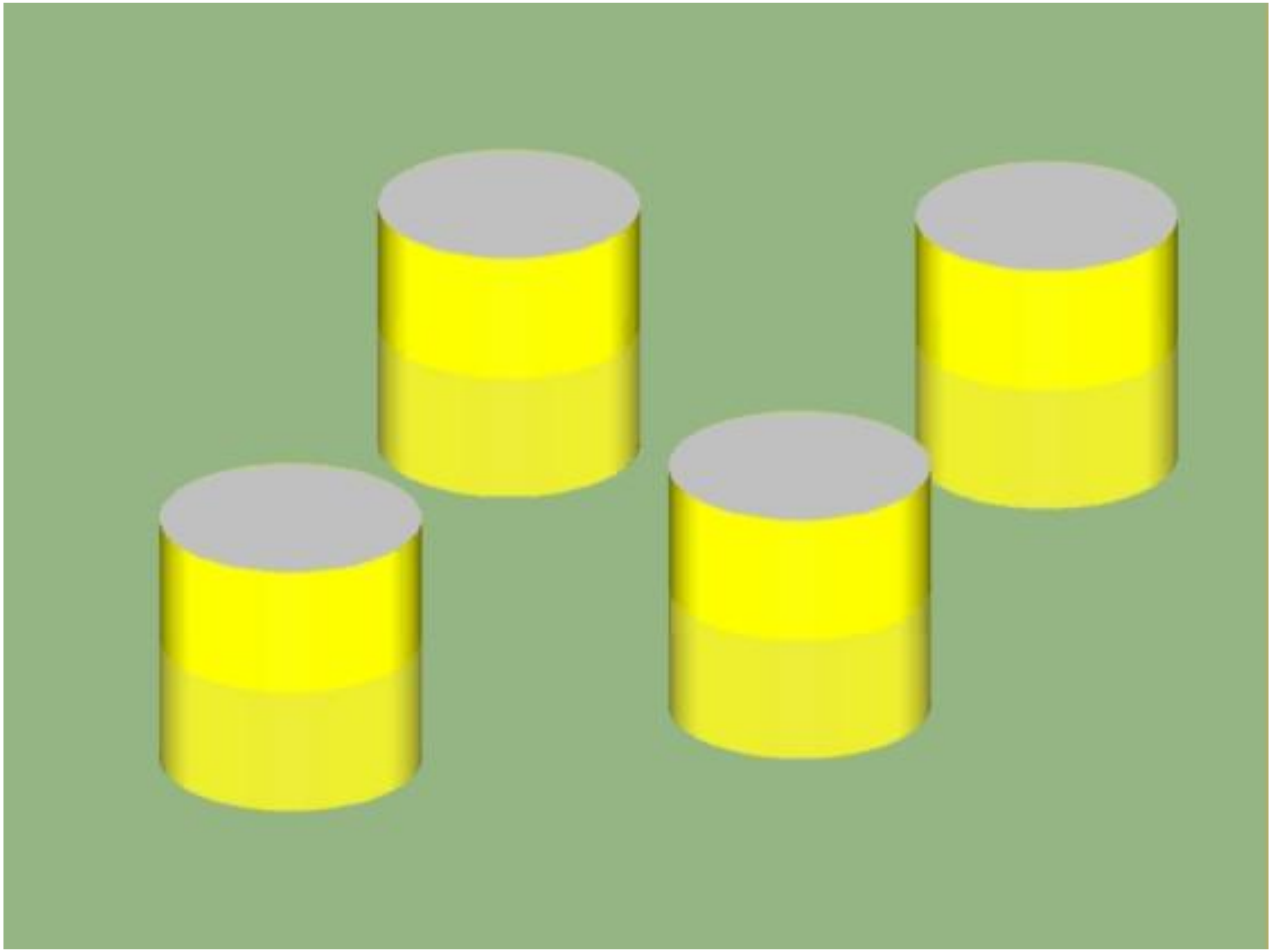
Wave-To-Wire Array Model



- Last year we presented a novel *bi-directional* wave-to-wire array model that we had developed.
- For the hydrodynamic part, we developed a new *time-domain* hydrodynamic wave energy converter array model.
- It takes into account *all* the hydrodynamic interactions between *all* the converters.
- It models *any number*, *shape* and *configuration* of devices in an array, each moving in up to 6 degrees of freedom.

Time-Domain Simulation of Four Buoys

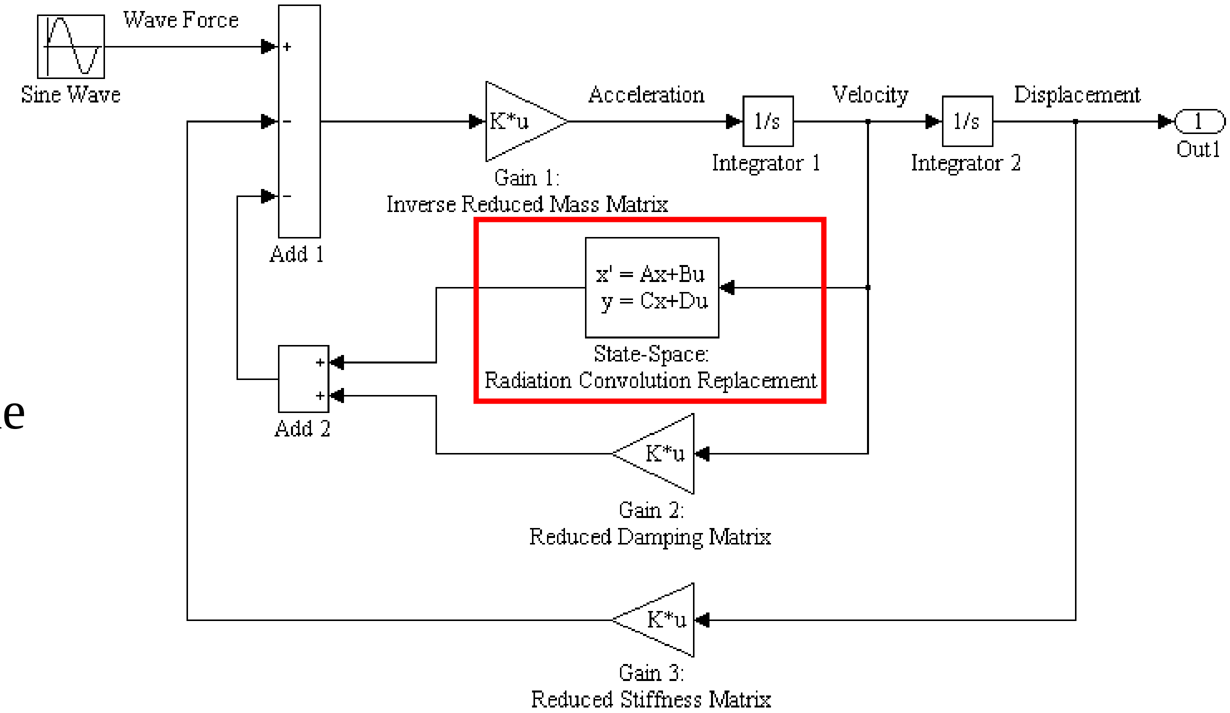


State-Space Representation of Radiation

- The hydrodynamic module is written in Matlab/Simulink.
- For the first time, a state-space system:

$$\dot{\mathbf{x}} = \mathbf{A}\mathbf{x} + \mathbf{B}\mathbf{u}$$
$$\mathbf{y} = \mathbf{C}\mathbf{x} + \mathbf{D}\mathbf{u}$$

has been used to replace the 'most difficult' radiation convolution terms in the equations of motion for an array.



- This state-space approach is well suited to enable up-scaling.
- There are many equivalent state-space systems and the choice is crucial to ensure numerical stability.

Stability of State-Space System

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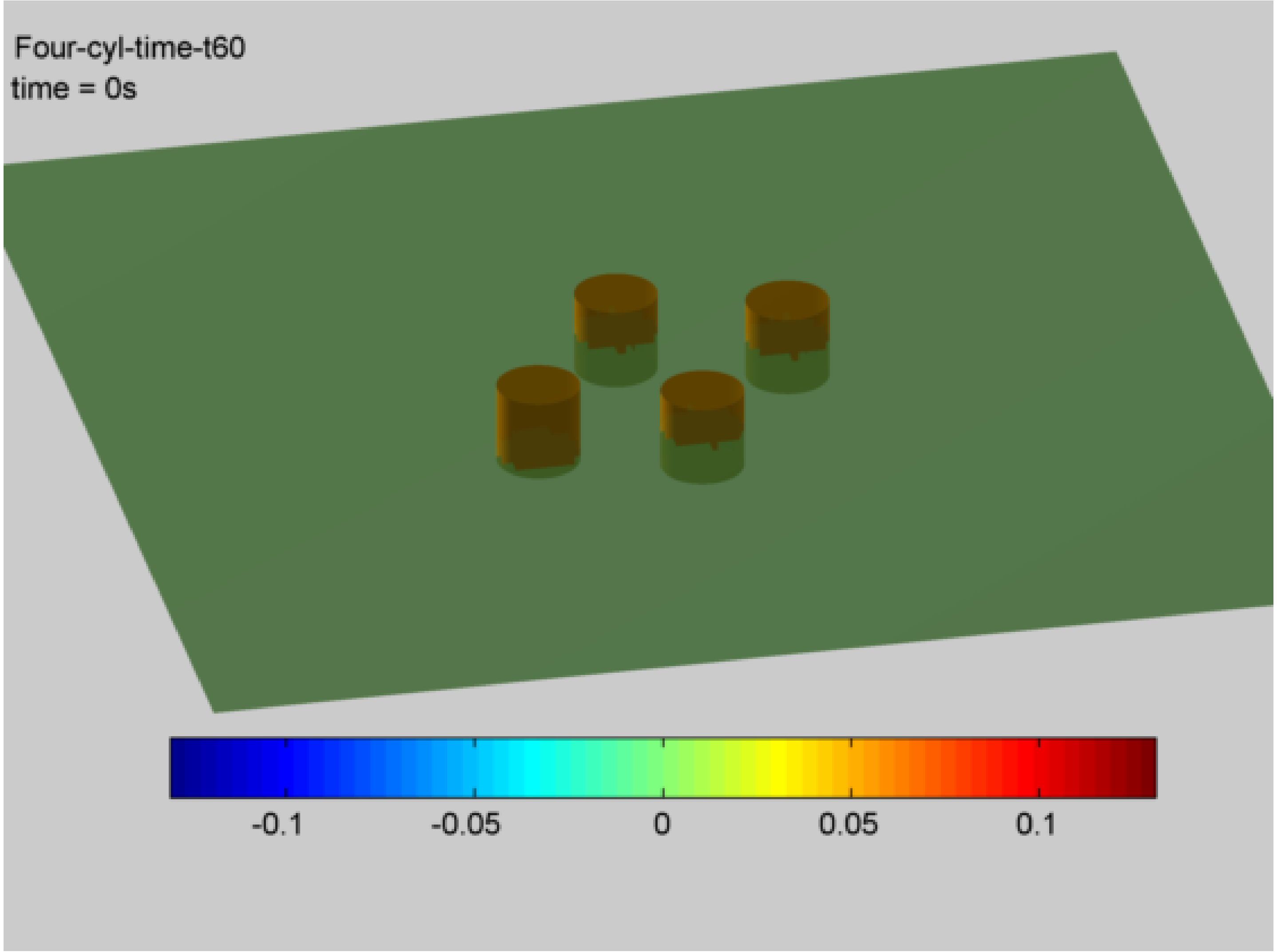
- The algorithm developed is designed to optimise the stability of the state-space system.
- For each array a number of parameters can be chosen to influence the best derivation of the radiation state-space system:
  1. *fit_error_max*: how well the frequency-domain data is approximated.
  2. *data_scaler*: it can be useful to scale the frequency-domain data.
  3. *max_ω*: the maximum ω used in the frequency-domain data.
- The condition number of the state matrix **A** is an excellent and robust measure of the stability of the system.

Results for a 4 Buoy (20 DoF) Case

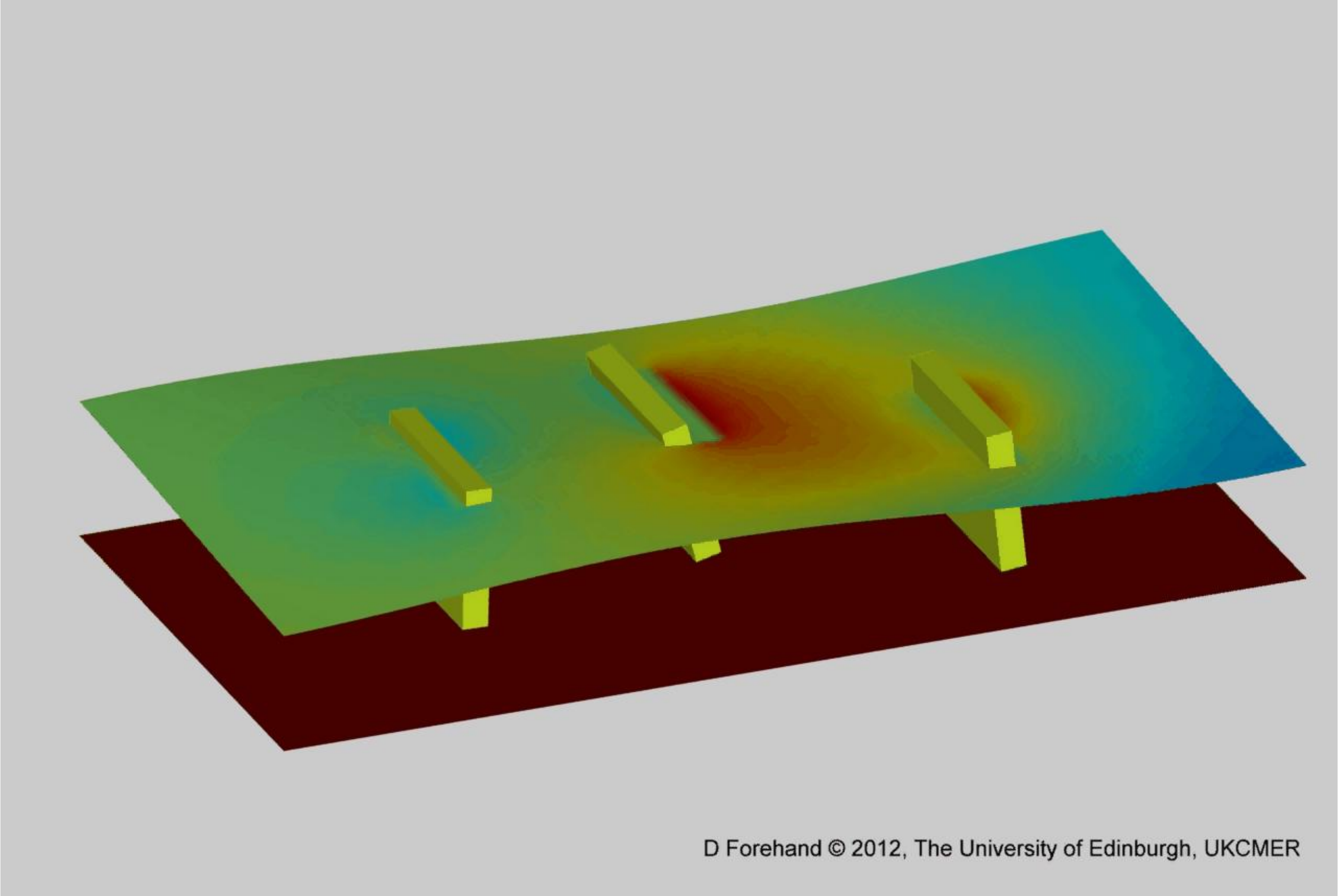
1st number: Order of state matrix **A** (Determined by no. DOFs and no. states)
2nd number: Maximum real part of the eigenvalues of **A**
3rd number: Condition number of **A** (cond(**A**) << 1,000,000 for stability)

	max_ω = 100% of original max_ω		max_ω = 90% of original max_ω		max_ω = 80% of original max_ω		max_ω = 70% of original max_ω	
	fit_error_max = 1×10^{-2}	*fit_error_max* = 1×10^{-3}	*fit_error_max* = 1×10^{-2}	*fit_error_max* = 1×10^{-3}	*fit_error_max* = 1×10^{-2}	*fit_error_max* = 1×10^{-3}	*fit_error_max* = 1×10^{-2}	*fit_error_max* = 1×10^{-3}
data_scaler = 1	**2880** -0.0860 **56.1**	**4232** -0.0166 **1.7×10^{7}**	**2759** -0.0861 **200.2**	**3664** -0.0615 **281.2**	**2444** -0.0846 **199.5**	**3328** -0.0918 **258.0**	**2296** -0.0864 **29.7**	**2956** -0.0909 **2.0×10^{8}**
data_scaler = 1×10^{-3}	**2880** -0.0860 **56.1**	**4232** -0.0166 **3.9×10^{8}**	**2759** -0.0861 **200.3**	**3664** -0.0615 **281.2**	**2444** -0.0846 **199.5**	**3328** -0.0918 **258.0**	**2296** -0.0864 **29.7**	**2958** -0.0911 **3.3×10^{9}**
data_scaler = 1×10^{-6}	**2880** -0.0860 **56.1**	**4232** -0.0166 **189.2**	**2760** -0.0861 **200.3**	**3664** -0.0615 **281.2**	**2444** -0.0846 **203.0**	**3328** -0.0918 **258.0**	**2296** -0.0864 **29.7**	**2961** -0.0913 **1.7×10^{10}**

Time-Domain Free-Surfaces



Arrays of Other Collector Forms (eg Bottom-Hinged Flaps)



SI for Dynamic W2W Modelling of a 48 Device, Sparse Wave Farm

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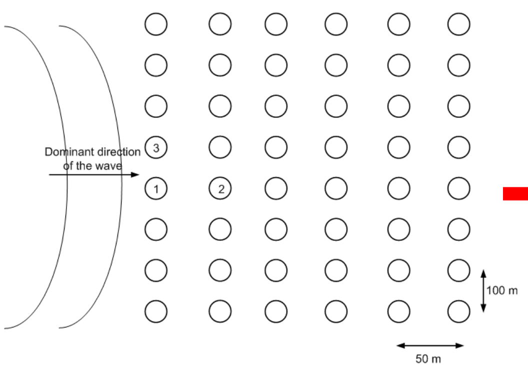
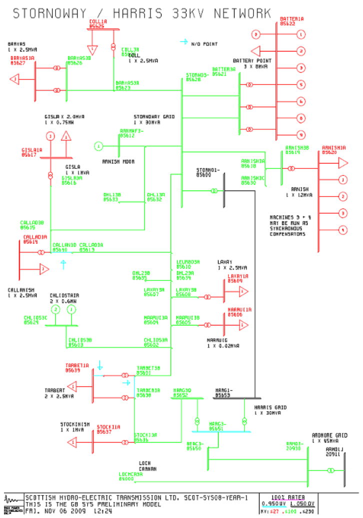
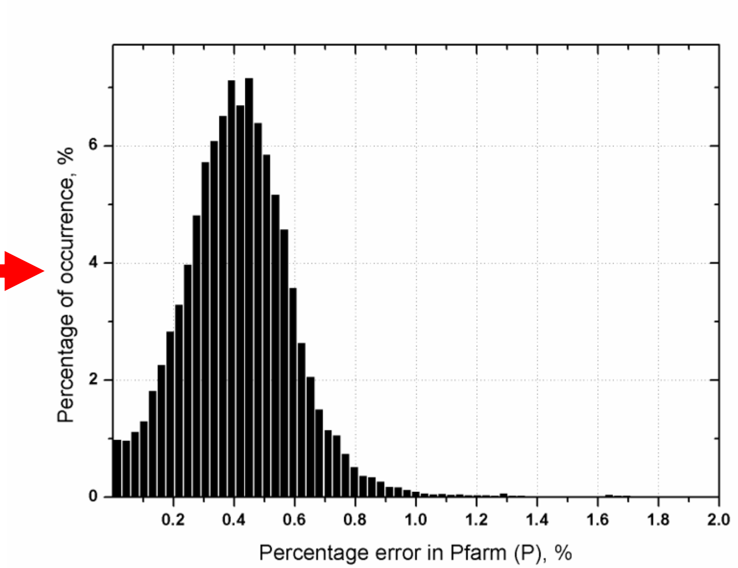
- Resource-to-wire model of several WECs required to correctly predict effects of real and imaginary power control on the electricity network power flow.

- Simulations of the detailed model of a large farm for electricity network impact studies require a high time resolution (few 10s of milliseconds).

- The detailed model of a large farm is computationally too intense to simulate extended operation, so individual devices are abstracted by machine learning models.







SI for Dynamic W2W Modelling of a 48 Device, Sparse Wave Farm

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- The individual WEC systems have been system identified and cloned to build models of 48 device farms.
- This leads to significant computational speed gain, and allows exploration of controlled response, with acceptable maintenance of accuracy and stability.

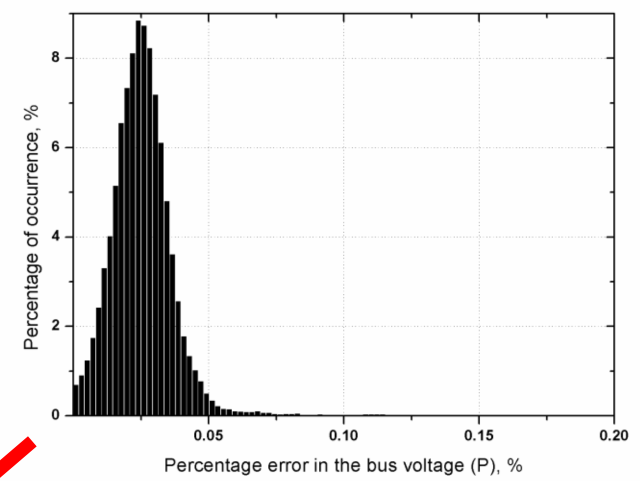

Table 4: Comparison of computational time used by the detailed and the NARX models

Simulation run	Simulation time-step (s)	Computational time detailed model (hrs)	Computational time NARX model (hrs)
6 MW farm 600-second run	0.1	1.5	0.033
6 MW farm 1-hour run	0.1	10.7	0.182
6 MW farm 5-hour	0.1	42.8	0.95
6 MW farm 1-day run	0.1	NA	4.4

Other Related Work

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- FLOWBEC: modelling tidal and wave action on single/multiple devices to predict impact on benthic communities.
- SDWED: comparing results of the W2W model with data from the Wavestar™ device.
- HydraLab IV: preparations for extended array testing in DHI tank.
- Led, co-wrote or provided input to several Grand Challenge and other international proposals – fingers crossed!

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Thank You!
& What Next!