Wave Energy Control in Practice

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wave energy SCOTLAND

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Specialists in Marine Energy & Technology

Introduction

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Control Perspective

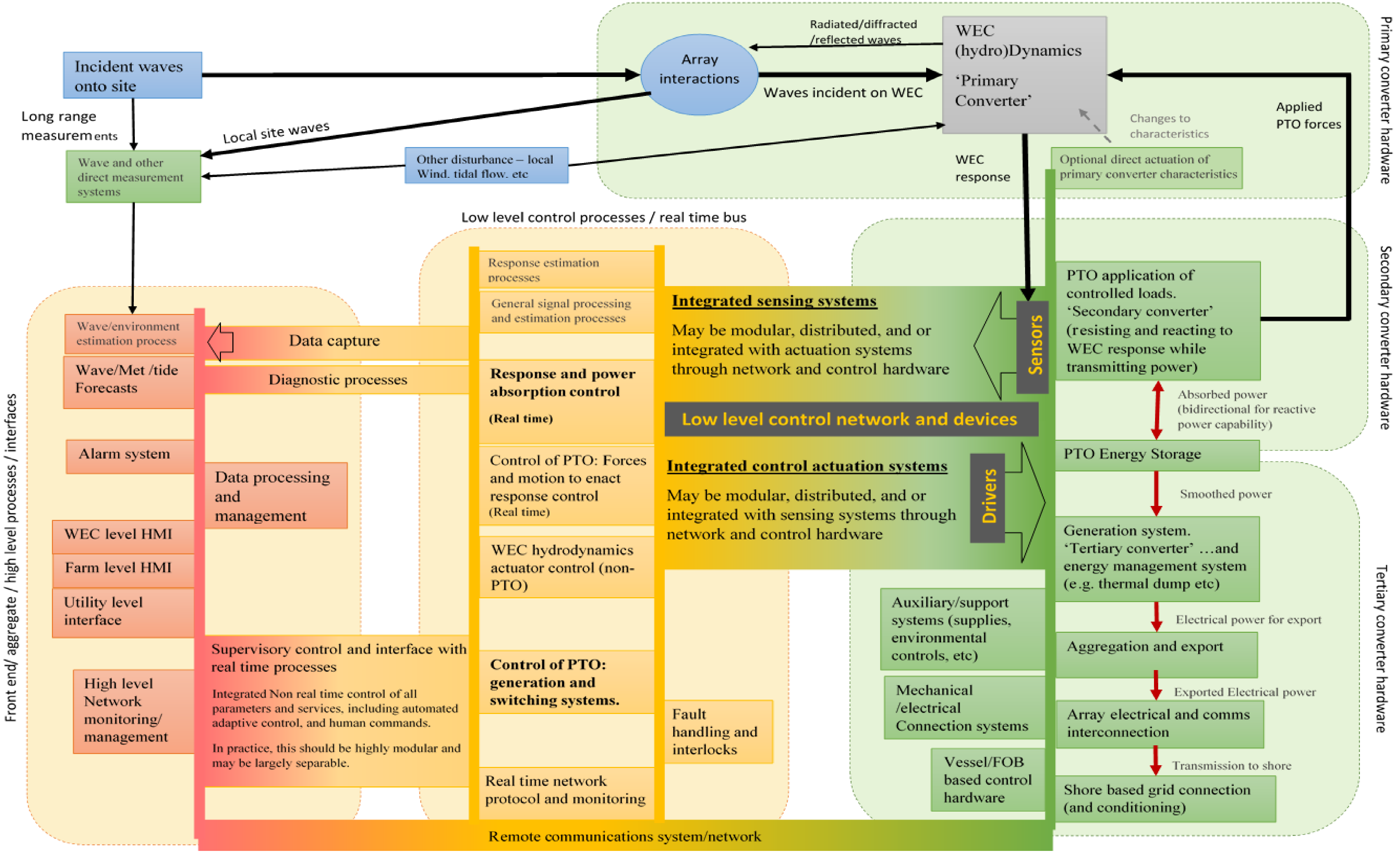
Wave energy is a dynamics and control problem

A control perspective aids understanding of functional requirements generally

Approach to ultimate performance limits needs sophisticated control

The control system is likely to drive a number of other system specifications directly, and vice versa…

General Control Framework



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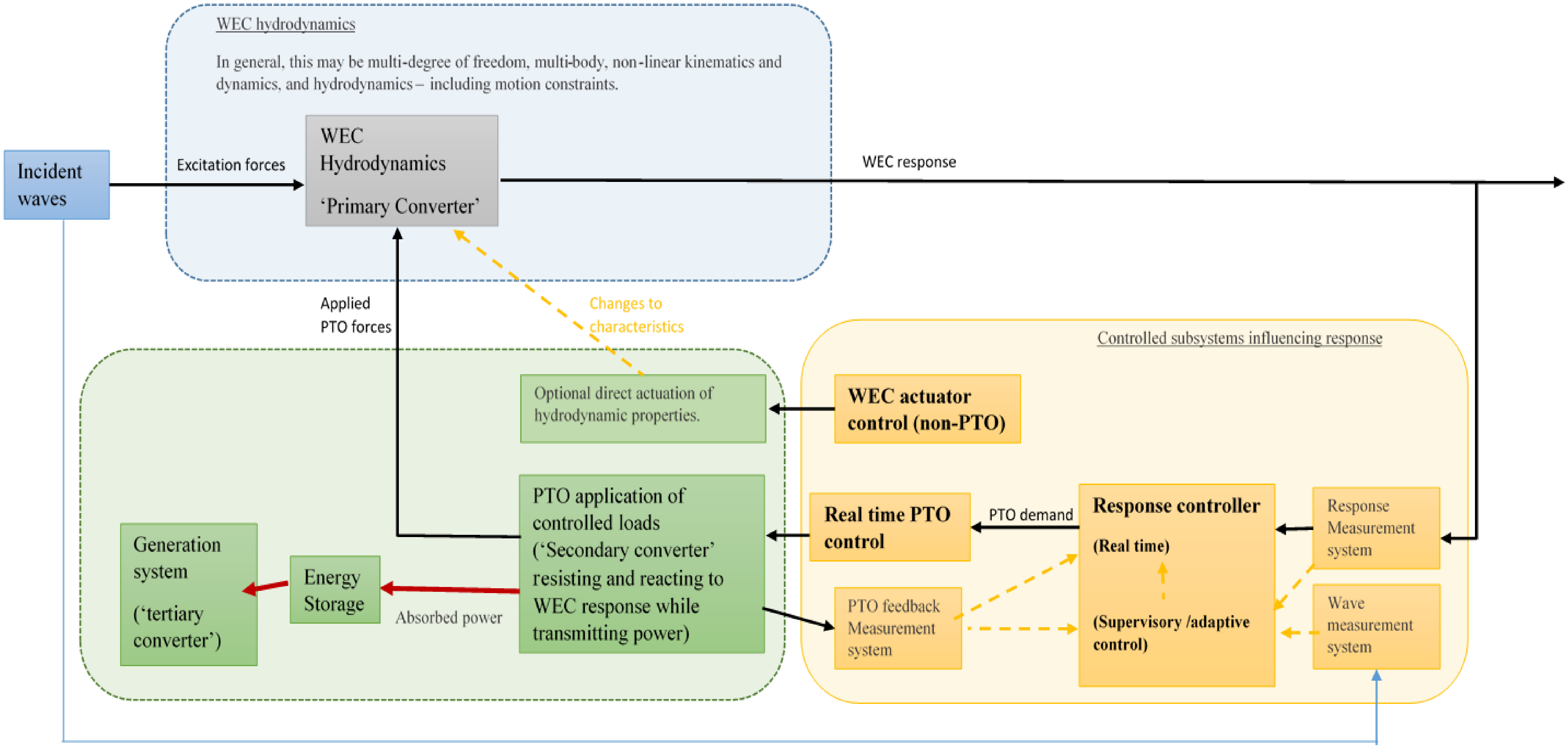
Practical implementation issues

- Control system can break machines if they go wrong! So must be robust.
- Typically a number of ancillary systems to be controlled
- Control system also provides remote operation, diagnostics, and fault handling – likely to be important for long term reliability and maintenance.
- Intimidate interaction of system and control development. Control is not something to add later.

- Common control platform throughout is cost effective and powerful:
  - Flexibility to adapt to new understanding, link systems, use new signals
  - Integrated signal processing, diagnostics, automated actions, alarms, etc
  - Common parts, expertise, data gathering and analysis

Response Control Framework



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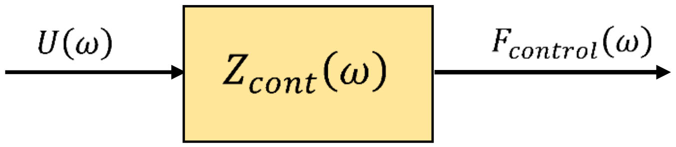
General Control drivers of PTO specification

- High 'gain' requirements for WEC application is challenging due to:
  - Delays in control actuation and measurement
  - Measurement noise and disturbance
  - Load path stiffness – lost motion and high frequency resonance
  - Any limits on rate of force change

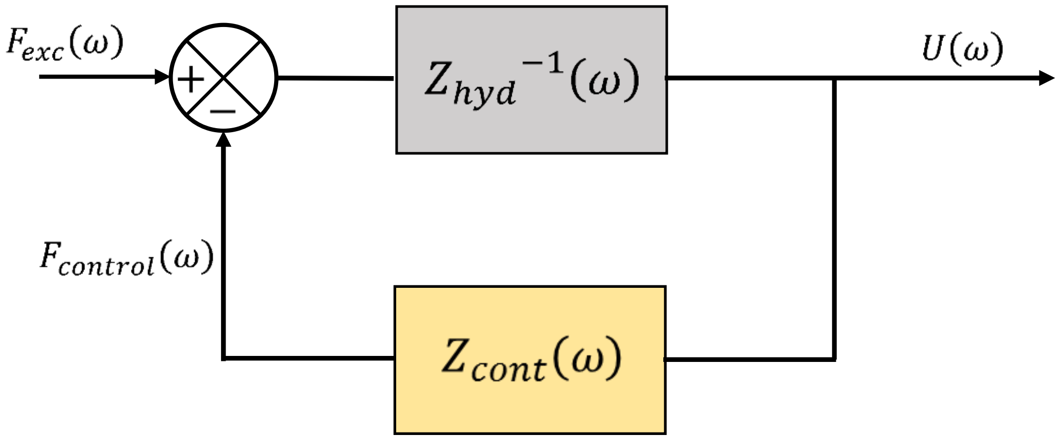
- But these issues are generally ignored in the wave energy control literature

Stability

Typical PTO control – Control for force output as a function of measured WEC response, which can be open loop.



WEC dynamic response to wave excitation and control (PTO) forces, also open loop.



But the controlled force is effectively a feedback term in the whole 'closed loop' dynamic system.

So whole system is subject to instability from features of the WEC, PTO, and control system in combination, governed by familiar feedback gain criteria.

Equation of motion: $\left(Z_{hyd}(\omega) + Z_{cont}(\omega)\right) U(\omega) = -aW(\omega) = F_{exc}(\omega)$

Control transfer function: $\dfrac{U(\omega)}{F_{exc}(\omega)} = \dfrac{Z_{hyd}(\omega)^{-1}}{1 + \left(Z_{hyd}(\omega)^{-1} Z_{cont}(\omega)\right)}$

Likely drivers of stability margin

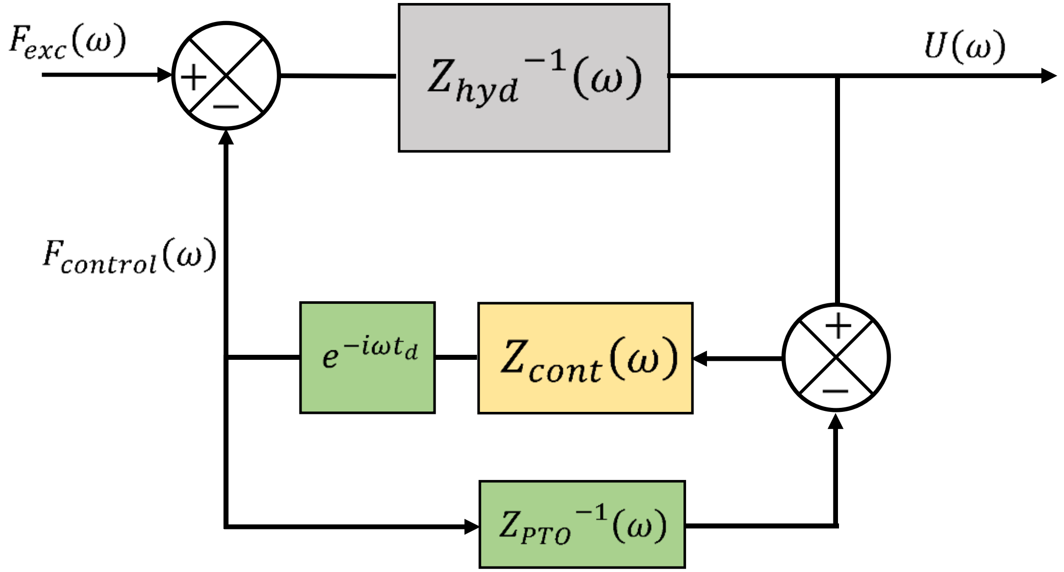
Delays in the control force path:

- Latency in control system itself – sampling, processing, output
- ‘Actuation Delays’ in PTO meeting control demand

Compliance in the controlled load path:

- Local Structural stiffness PTO components and WEC local structure.

NB – magnified greatly by measurement issues if influenced by local compliance
=> Placement and distribution of sensors may attenuate self-disturbance

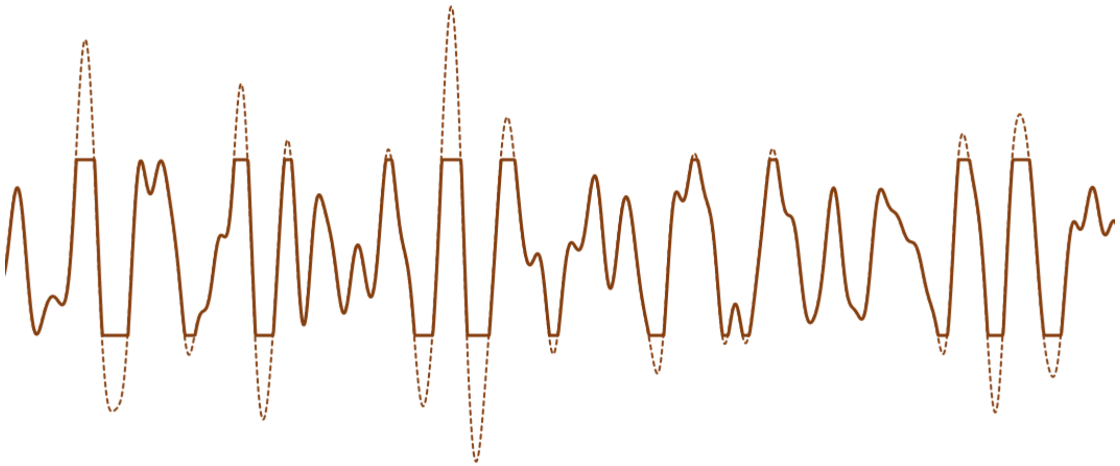


Non-linearities and constraints

Classical approach very useful conceptually.
But practical systems tend to have strong non-linearities so numerical modelling generally required.

Load and motion constraints:

- Load range is expensive, so may be motion range
- Design is driven by compromise of these costs against energy capture
- Control needs to take full account of this
- Overall design optimisation needs to couple control based performance outcomes with engineering design and cost drivers.



Loss modelling

- Control optimisation depends on the loss profile of the PTO
- There is a trade off between losses and power capture to maximise generated output

- Reactive power requires efficient energy recovery and transmission – this is more important for some WEC types than others.
- The practical effectiveness of reactive power depends particularly heavily on the loss profile of the PTO system under control

- This means including the loss profile of the energy storage system which is likely to be hysteretic and relatively complicated to model

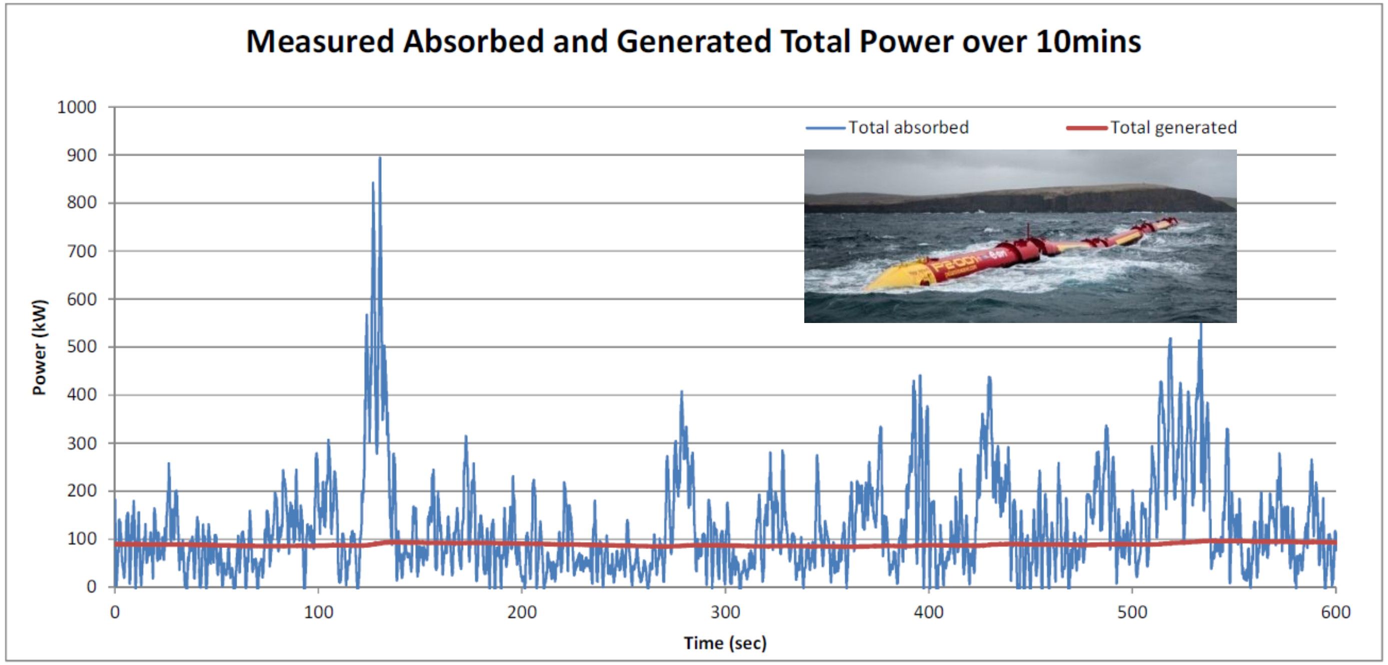
Generation smoothing control

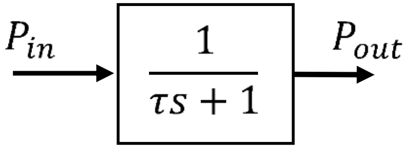
Grid demands smooth power and 'grid code compliance'.
Related PTO specifications are driven by the costs of output rating vs energy storage.

The wave envelope has very long periods, therefore so must the output, but the power range can be attenuated by smoothing.

The range of the output (and hence rating) tends to be proportional to the energy storage volume via smoothing time-constant.

1st order smoothing is equivalent to proportional control of stored energy around a set point…





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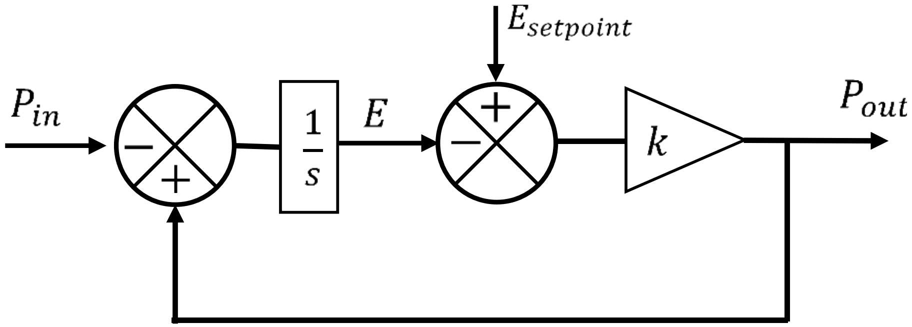

For $\tau = \frac{1}{k}$

and fixed $E_{setpoint}$

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The gap

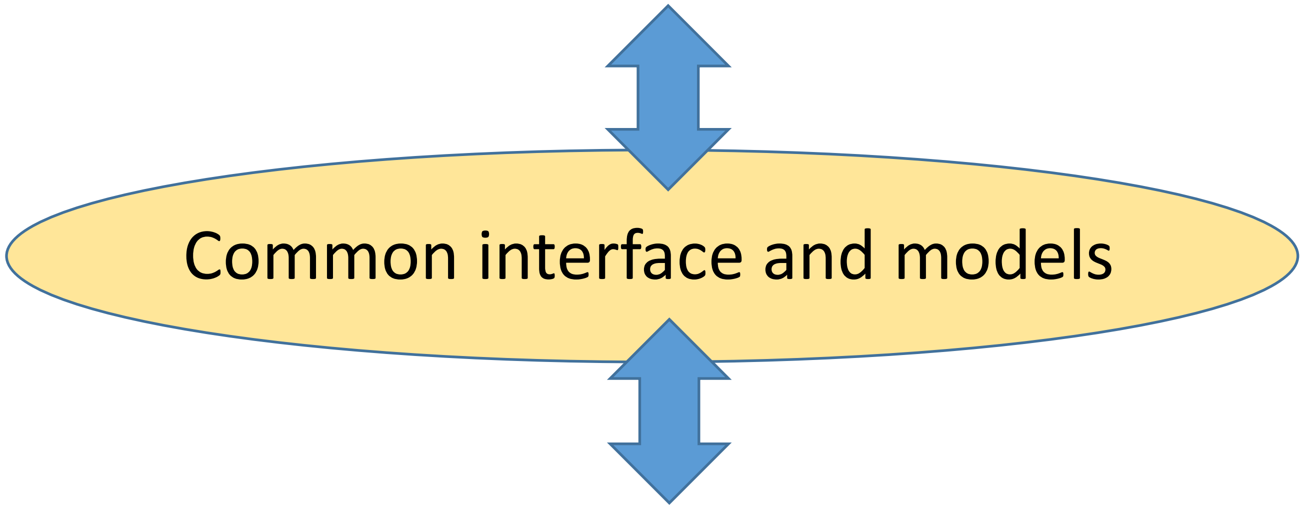
The high level theory of WEC control for absorption has been well defined for decades, but a gap remains between theory and practice

1. Theory tends to ignore the implementation issues that muck it up
2. A lack of full operational exposure allows some control drivers to be ignored by technology developers

So a mutual appreciation of control issues and their engineering drivers is required to progress

Collaboration between technology and control developers

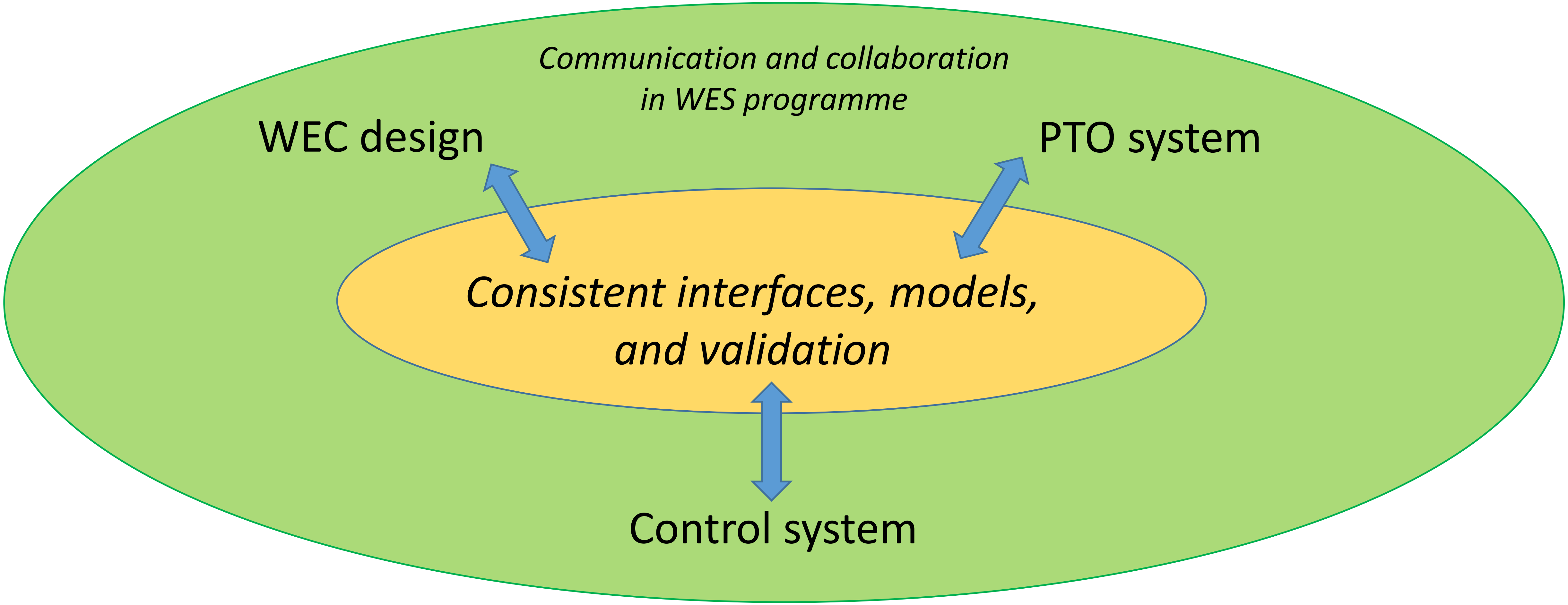
Technology hardware (WEC and PTO) developers need to understand and appreciate the control background drivers to what they are doing.



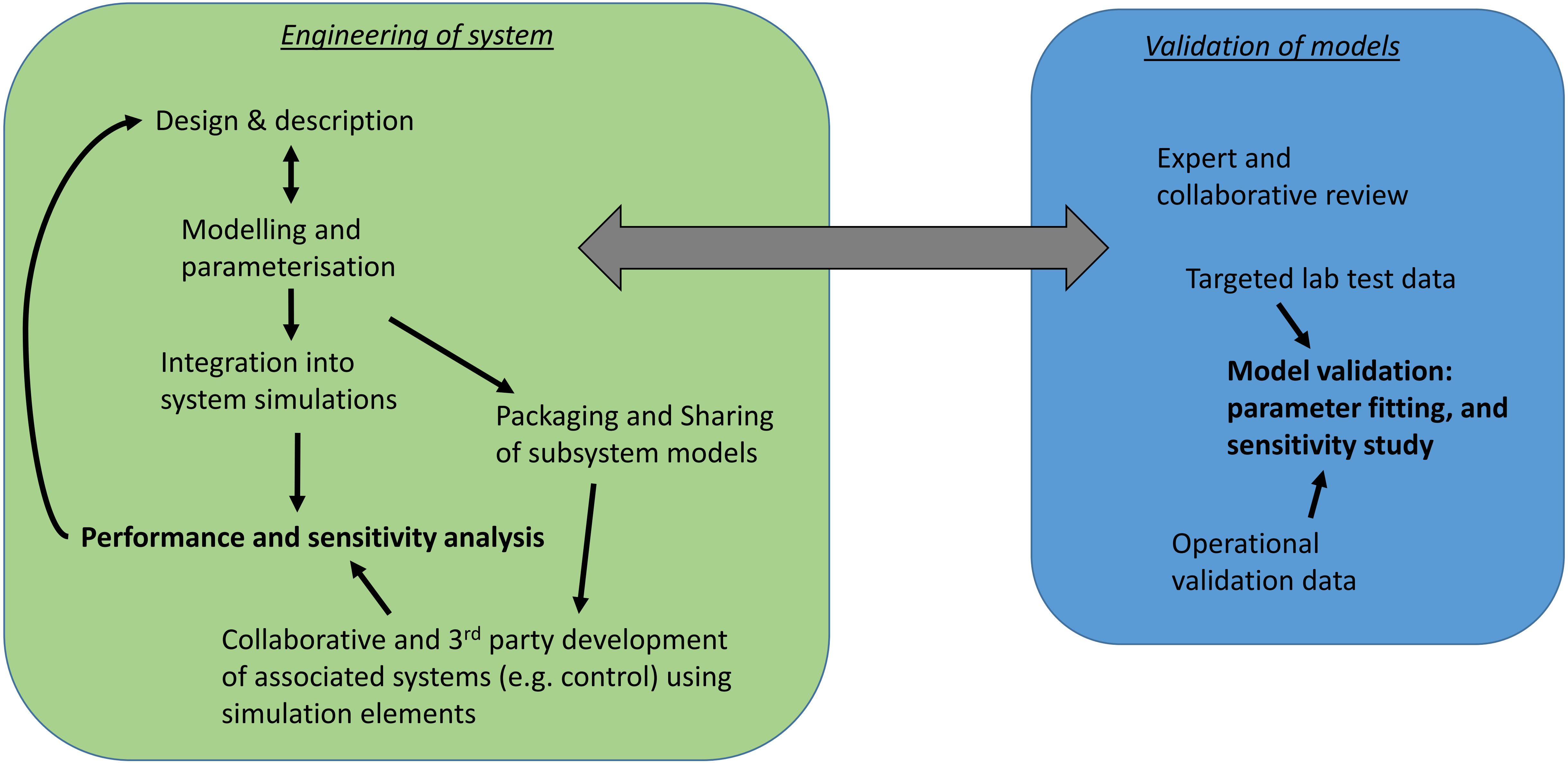
Control developers (methods, algorithms) must understand and be able to model the driving characteristics of real WEC and PTO systems.

Common modelling framework

Developers must communicate in mutually intelligible language to allow their systems to be a platform for others to integrate and build on



Engineering, Modelling, and Validation process



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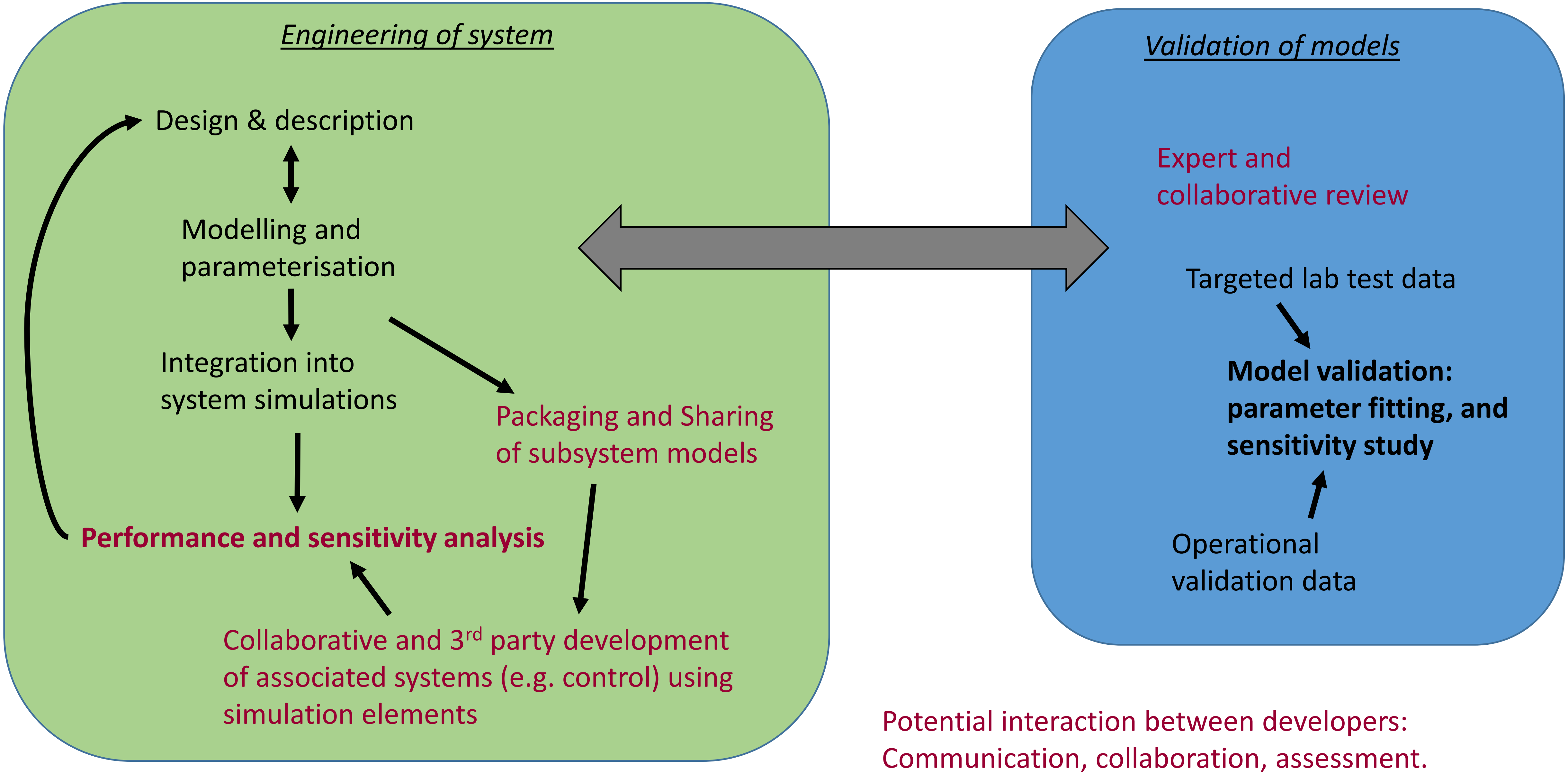

Potential interaction between developers:
Communication, collaboration, assessment.

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Closing

Overall control has a complex set of engineering sensitives and requirements demanding attention from all technology developers – not just those intending to develop control systems.

‘A Wave Energy Converter is a control system’

We want to engender: A good background knowledge of the control landscape in general terms, and Communication of control drivers and specifications between developers.

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