ETIPOCEAN

European Technology & Innovation Platform for Ocean Energy

Technology Theme Webinar

Control systems for improved yield, reliability and survivability

Tuesday June 27th 2017

Agenda

Chair		Speakers		
David Bould		Ross Henderson	Jochen Bard	Boris Fischer
Research Associate in Marine Energy		Senior Consultant Engineer	Head of Marine Energy	Expert Scientist
The University of Edinburgh and ETIP Ocean		Quoceant Ltd.	Fraunhofer IWES	Fraunhofer IWES

Questions and comments from the audience

Previous and upcoming webinars

Date	Theme	Subject	Speaker(s)
06/04/2017	Technology	Metrics and stage-gate development programmes	Jonathan Hodges (Wave Energy Scotland)
25/04/2017	Finance	Warranties, guaranties and insurance	Michael Bullock (Renewable Risk Advisors) Remi Gruet (Ocean Energy Europe)
23/05/2017	Environment & Socio-economics	Enhancing social impact and acceptance	Sue Barr (Open Hydro) Bruce Buchanan (Marine Scotland)
29/08/2017	Environment & Socio-economics	Minimising negative environmental impacts	Sabella EMEC

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Wave Energy Control

Ross Henderson, Quoceant Ltd

Practical experience of controlling Pelamis WEC

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Practical experience of controlling Pelamis WEC

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- Multi-Input-Multi-Output Control of response and power absorption
- Decoupled power smoothing and generation control
- Integrated diagnostics, alarms, and fault handling
- Further layers of data capture and handling

The role of control – real time

- Response and power capture: Measure the WEC response motion and apply loads through the Power take-off system. (actuators may also dynamically adjust the WEC geometry)
- This process allows for maximisation of the power capture of a given WEC, intrinsically limited by the WEC design through many cumulative factors

- Generation control: measure the power coming in and use short term storage to provide smoothed generated output

- The low level power transmission and actuation systems that enable this themselves typically require many real time control processes.

Generalised Response Control Framework

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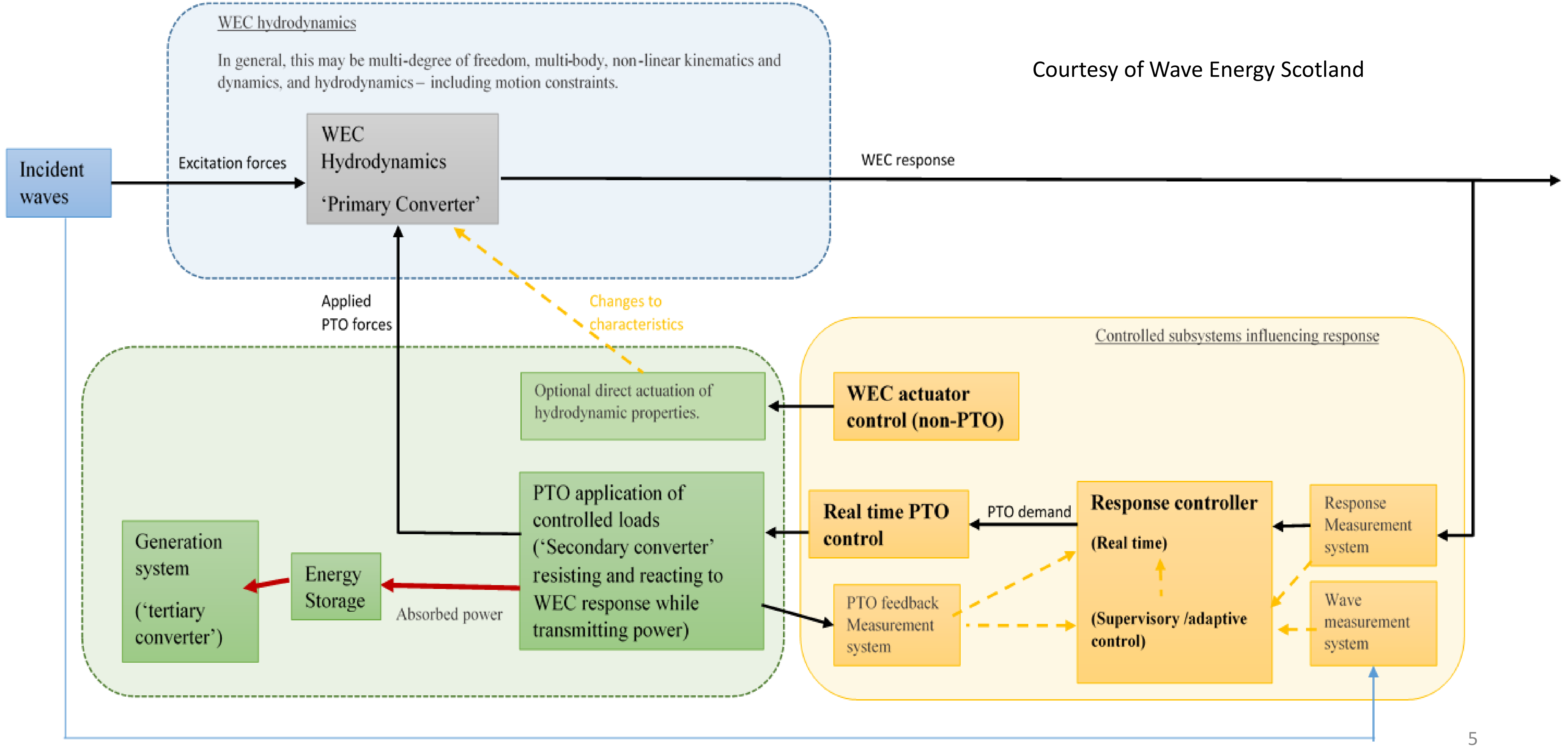
Courtesy of Wave Energy Scotland



The role of control – other aspects

- Electrical systems require robust and fault tolerant controls for grid integration
- Typically a number of ancillary systems must be controlled – e.g. thermal management, power supplies, environment, etc. often not fully appreciated early on in development

- Control system also provides data capture, diagnostics, alarms, and user interfaces.
  - These enable normal operation, fault handing, and offshore operations
  - Also efficient initial assembly & commissioning, and ongoing maintenance.

Practical implementation

- A common control platform throughout is cost effective and powerful.
  - Flexibility to adapt to new understanding, link systems, adopt new signals
  - Integrated signal processing, data capture, diagnostics, automated actions, alarms
  - Common parts, expertise, data gathering and analysis

- Control is embedded throughout systems so it must be included at design stage
- Control systems can break entire machines if they go wrong!

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 omit the implementation issues that complicate it
2. Lack of operational exposure allows vital constraints to be ignored by technology developers

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

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‘A Wave Energy Converter is a control system’

Successful WEC design demands a ‘control mindset’

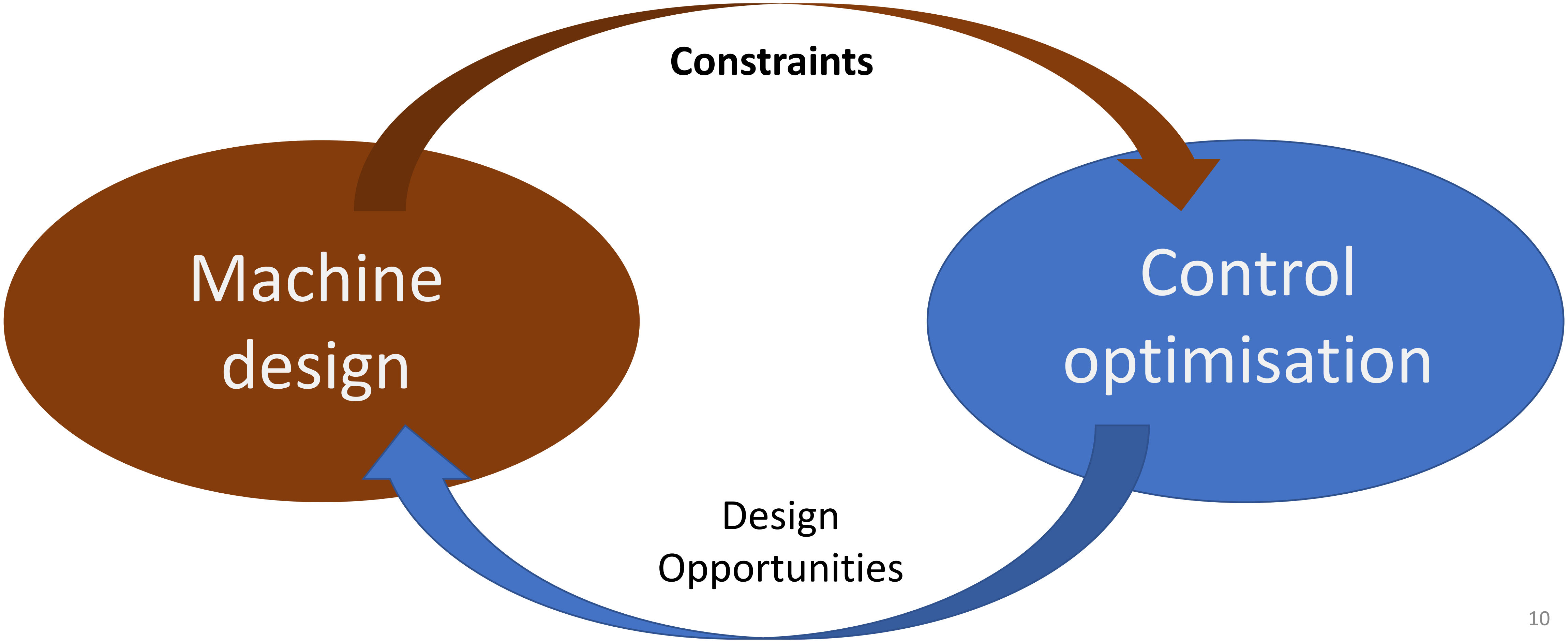
– You cannot properly design a WEC without consideration of its whole-system dynamics including response control & power extraction.

- *Design opportunities are revealed by the demands of an optimal controller and optimal power capture*

Also, Control developers must understand and work within practical constraints

- or they’re just recycling the existing idealised theory.
- *What is the performance impact of different Force and Motion ranges, realistic system dynamics and sources of reaction, Measurement disturbance, etc ?*

Optimising overall WEC design for Cost of Energy



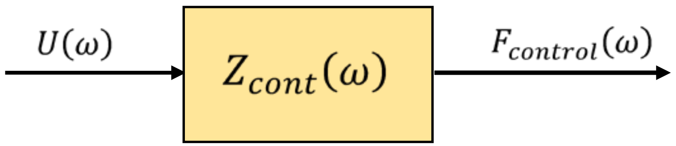
Constraints on control performance

- 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

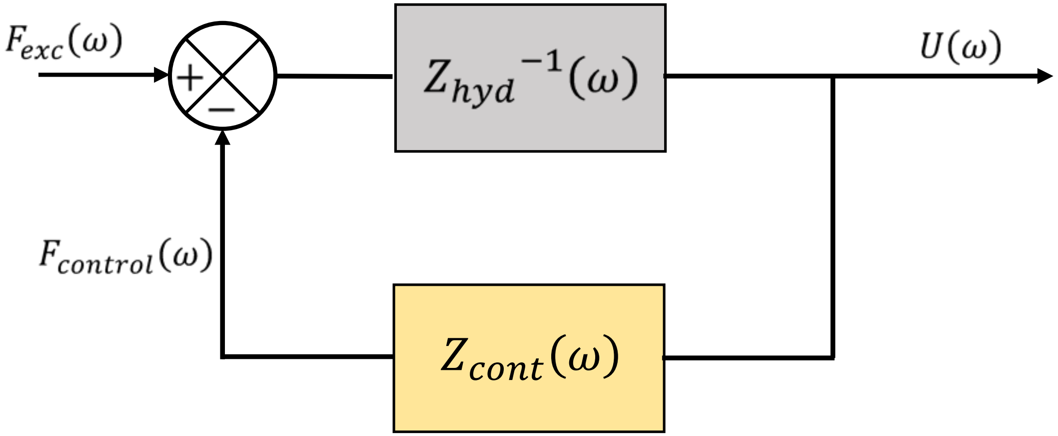
- These issues are generally ignored in the wave energy control literature based on an idealised mathematical framework
- But they tend to define the performance limits so sensitivity should be understood early on

Stability can be a major performance constraint

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.

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

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

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

Causes of stability limitiations

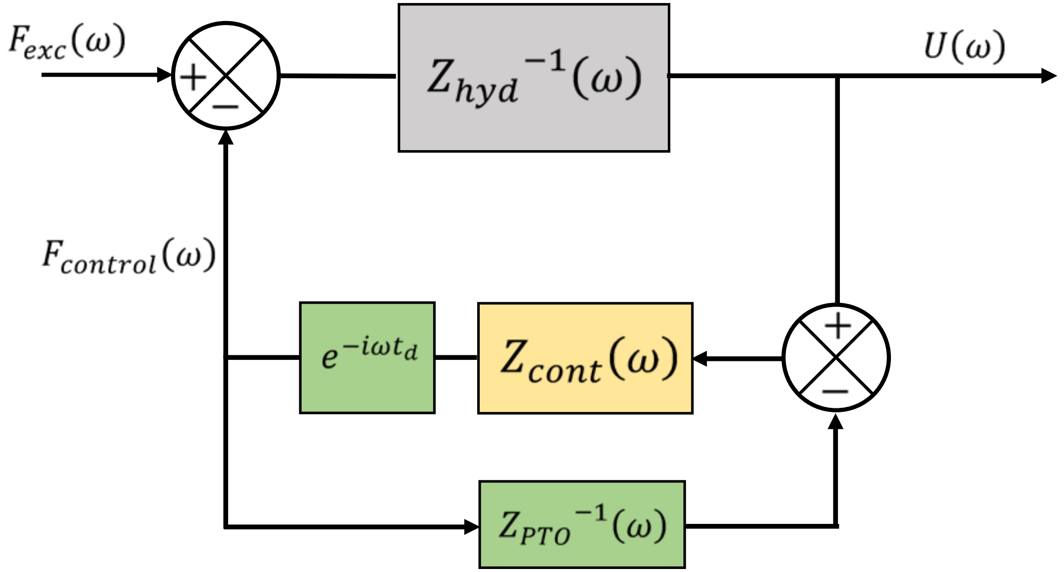
Delays in the control force path:

- 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

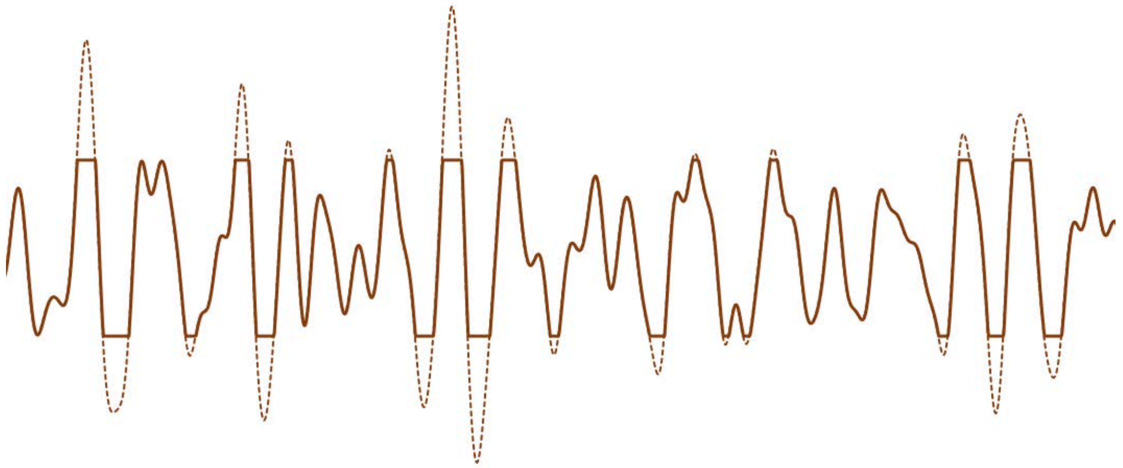


Nonlinearities and constraints

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.



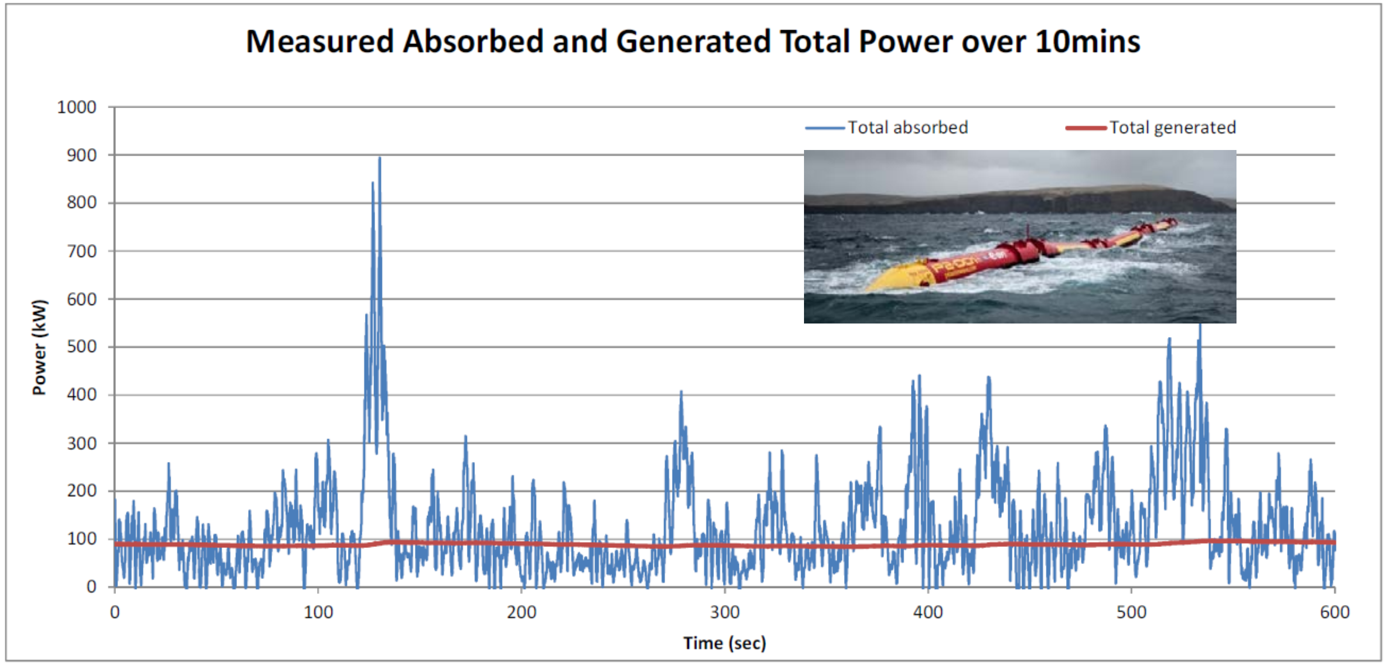
Generation control

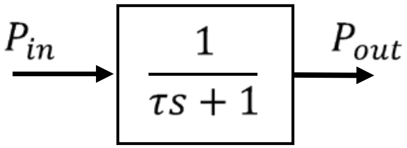
Grid demands smooth power and ‘grid code compliance’.
Related PTO specifications are driven by the costs of output rating vs energy storage.

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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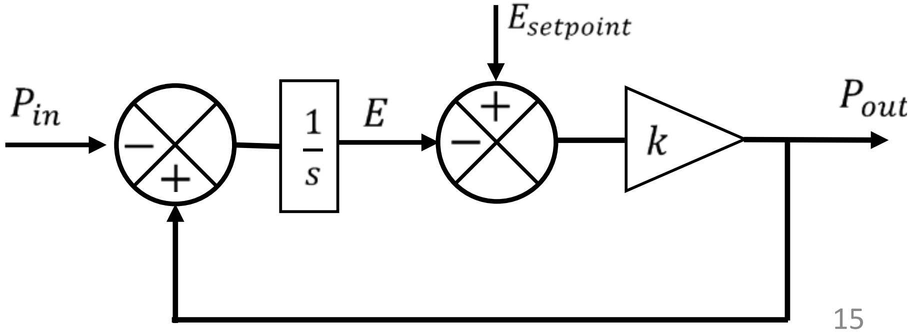


For $\tau = \frac{1}{k}$

and fixed $E_{setpoint}$

Collaboration between developers

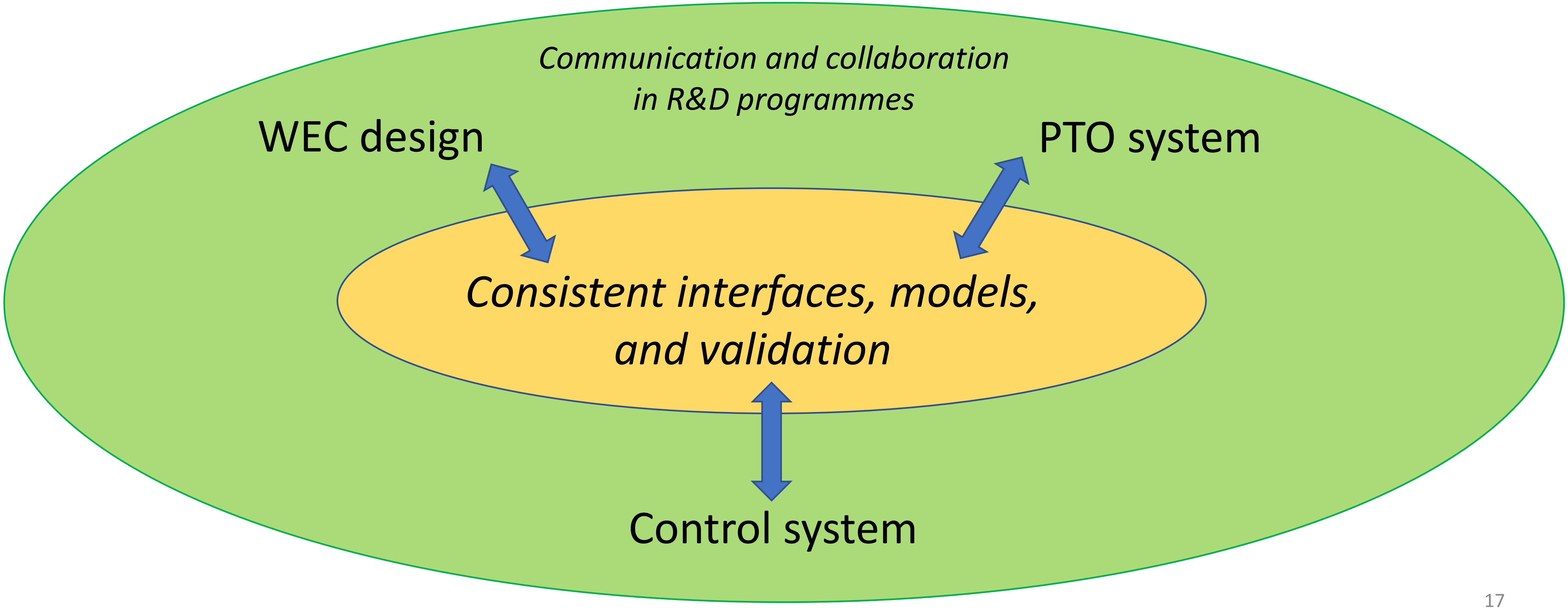
Technology hardware (WEC and PTO) developers need to understand and appreciate the control background drivers to what they are doing.

Common interface and models

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

Collaborative Control and modelling framework

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



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Thank you

Wave Energy Control

Ross Henderson, Quoceant Ltd

Control systems for improved yield, reliability and survivability: tidal energy converters

Photo: Ana Brito Melo

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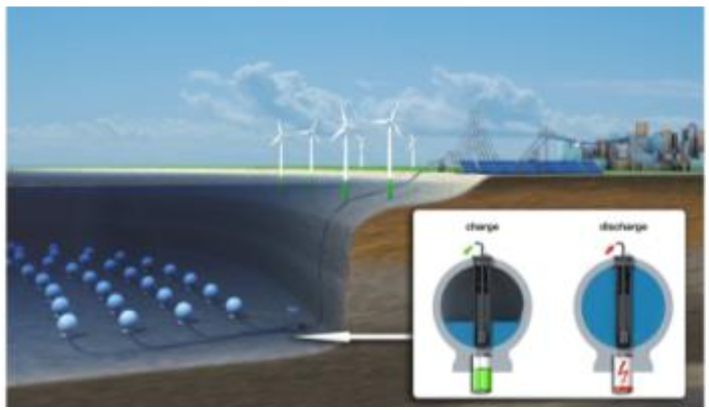
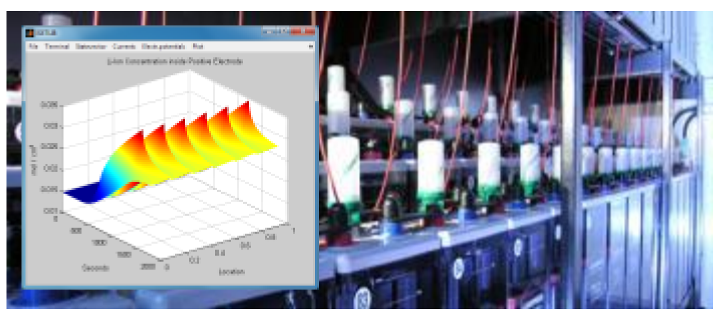
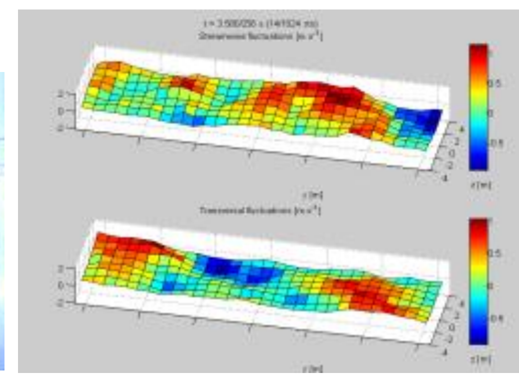
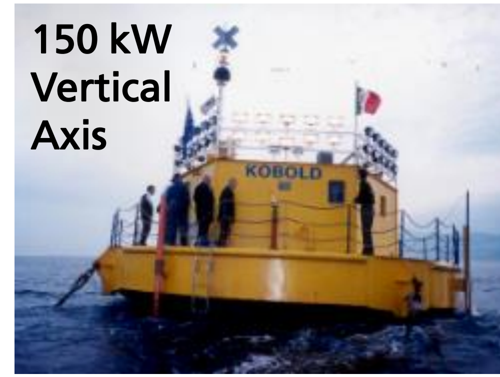
Control Engineering Department





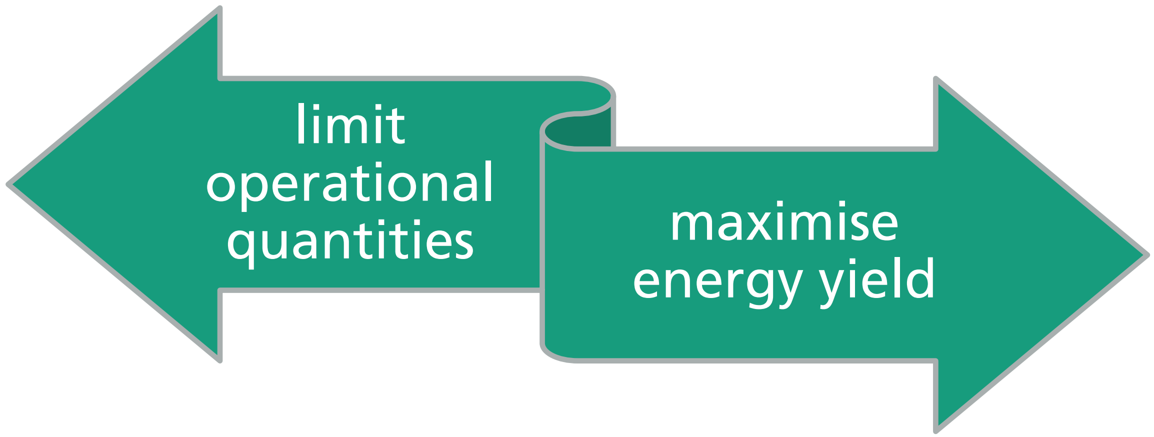


Examples for OE technology developments



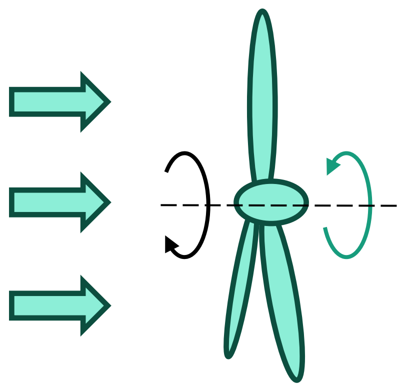
A tidal energy converter's control system…

…has to meet two competing goals



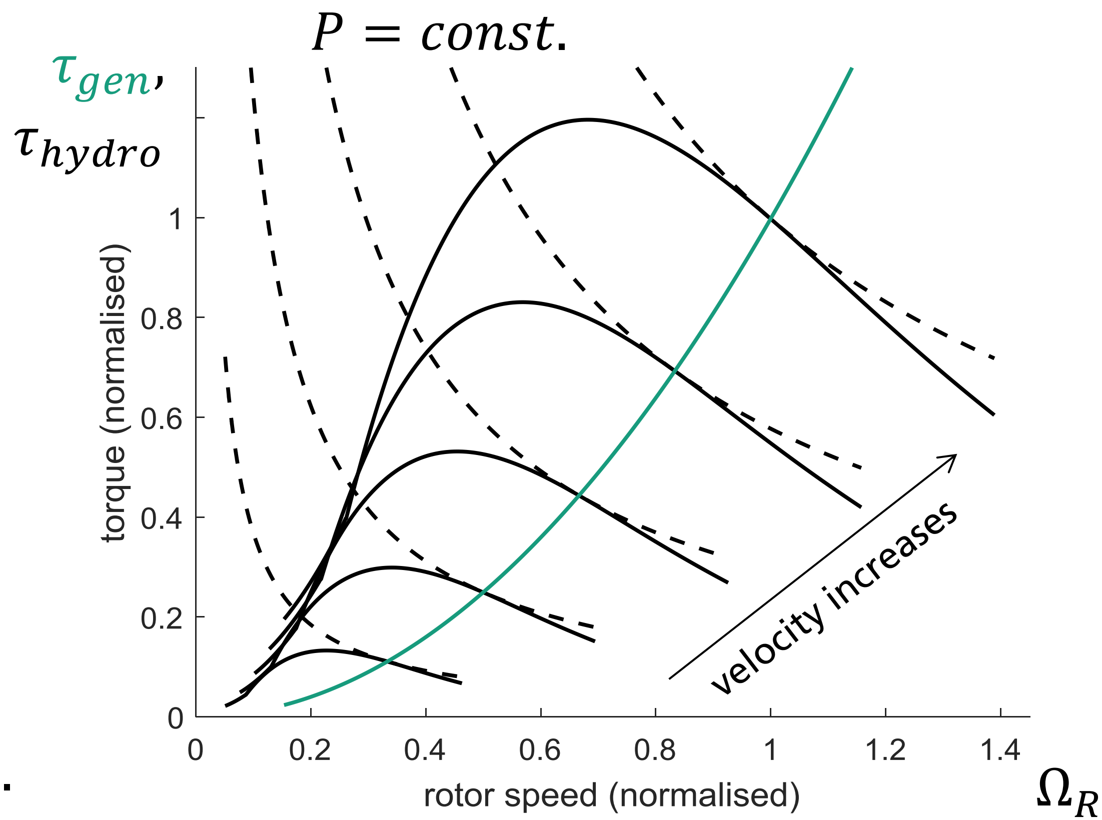
operational quantity	physical constraint
rotor speed	voltage of generator and converter, structural loads
generator power	current and temperature of generator and converter
pitch angle	duty cycle of pitch system

The Square-Law: Maximise energy yield



constant, homogeneous field of velocity

maximum hydrodynamic efficiency $\frac{\Omega_R}{v} = const.$



$$P_{hydro} \sim v^3 \;\Rightarrow\; \tau_{hydro} \sim v^2 \;\Rightarrow\; \tau_{hydro} \sim \Omega_R^2 \;\Rightarrow\; \tau_{gen}(\Omega_R) = K^* \cdot \Omega_R^2$$

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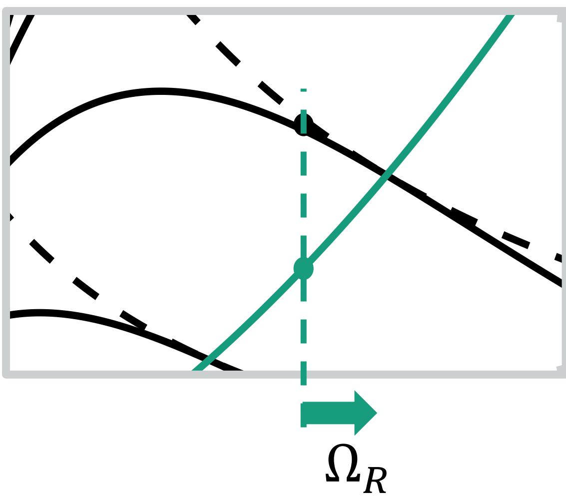
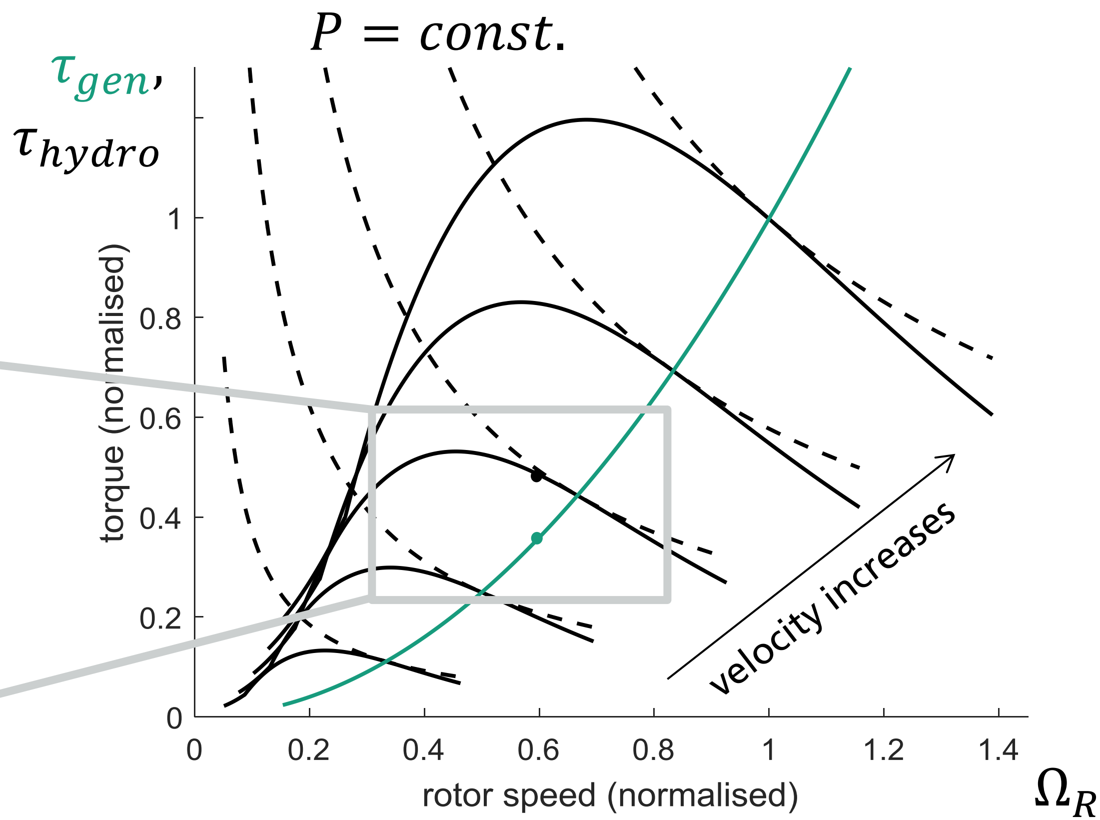
The Square-Law: Stability

$$\dot{\Omega}_R = \frac{1}{J_R}\left(\tau_{hydro} - \tau_{gen}\right)$$





For stationary currents: Rotor speed converges to optimum operating point

$$\tau_{gen}(\Omega_R) = K^* \cdot \Omega_R^2$$

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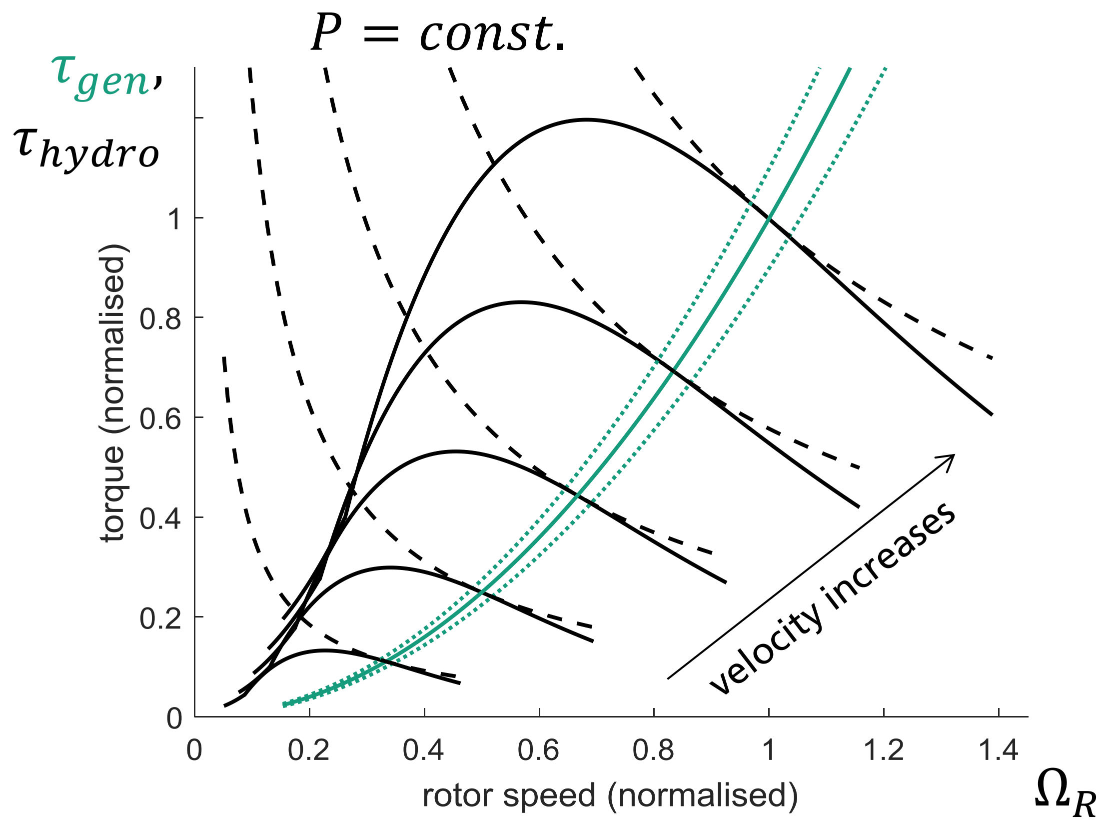
The Square-Law: Robustness

Stationary:

- K^* varies ±10%
- Power loss < 0.2%

Non-Stationary:

- < 3% of energy lost
- highly transient, bi-directional power flow with unrealistic amplitudes to gain this last bit

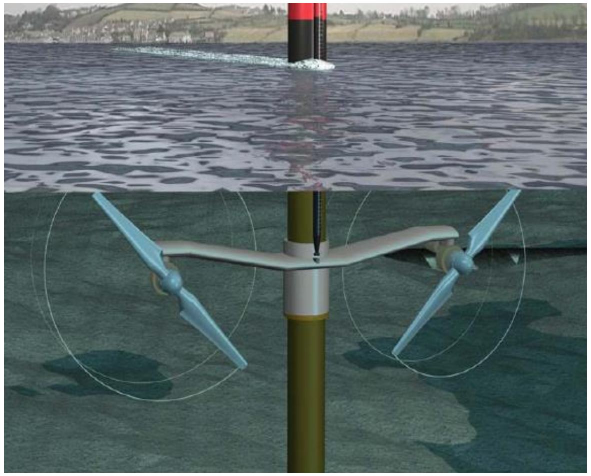


Square-Law is robust, stable, stationary optimal and simple!

$$\tau_{gen}(\Omega_R) = K^* \cdot \Omega_R^2$$

Controls for wave and tidal devices differ in…

- impedance vs. resistive matching
- power output variability
- adaptation to changing resource conditions
- extreme conditions
- transfer know-how from wind turbine control



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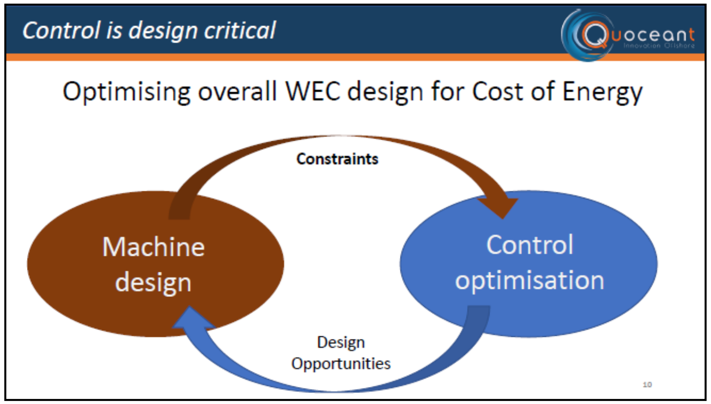
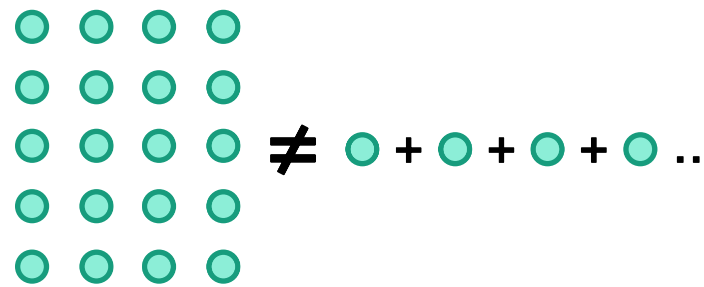
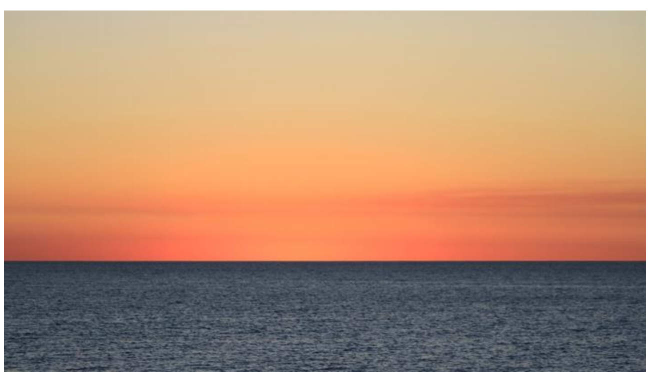
Controls for wave and tidal devices have a lot in common



- strong interaction between control and structural design



- interference between single units in arrays



Remoteness

- autonomous operation
- minimum maintenance

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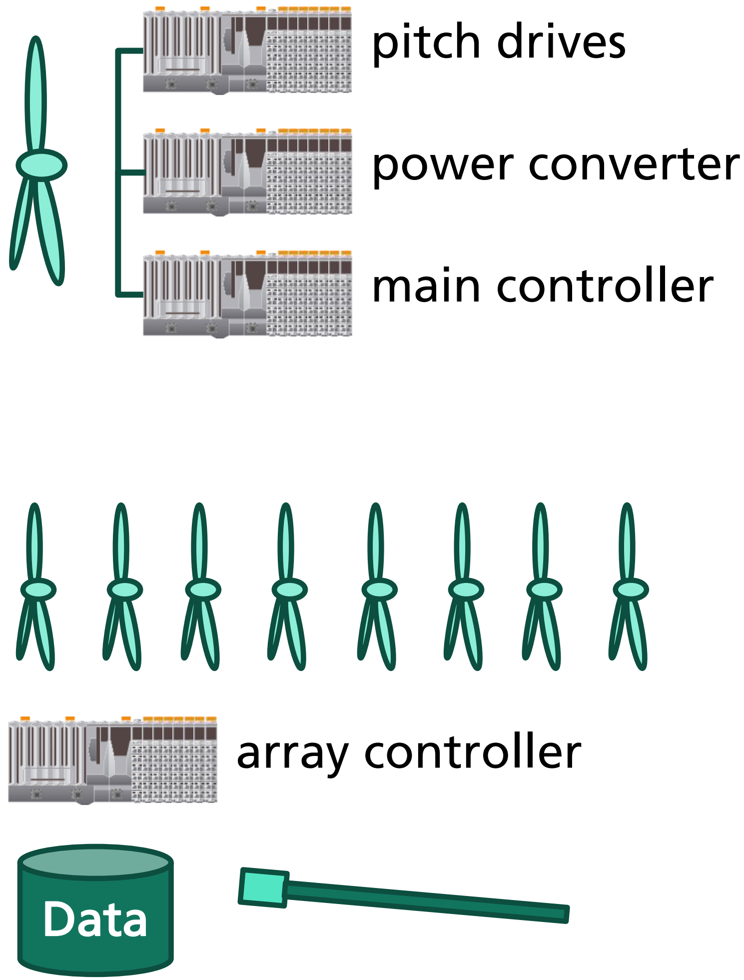
Hard- and software system



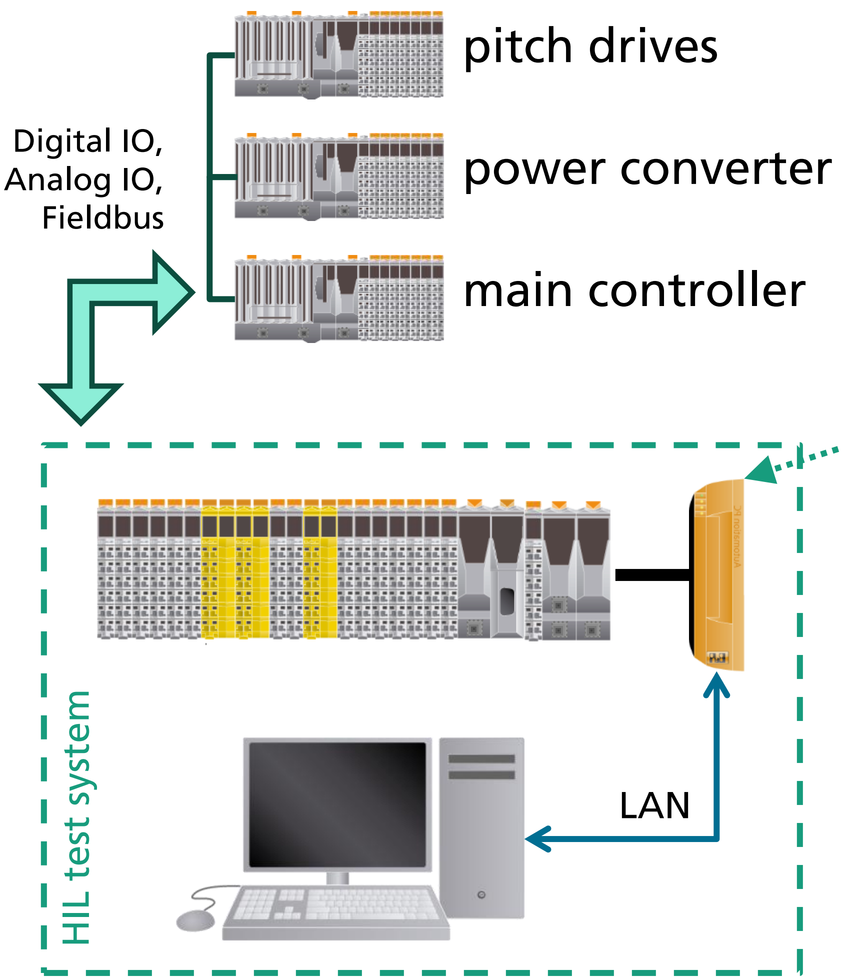
Distributed control system

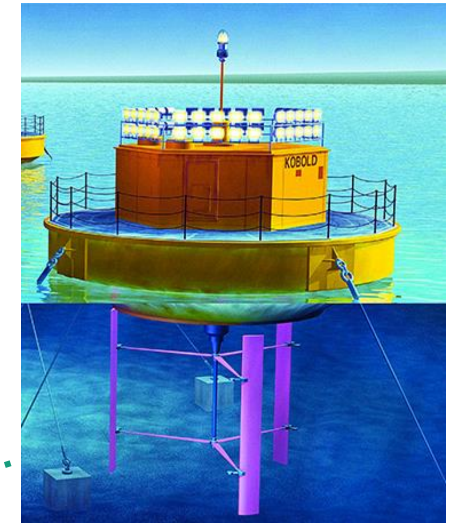
- several controllers
- field bus connection
- real-time system
- data storage
- remote access

Reduce the engineering effort related to the control system by making use of

- uniform information models and interface protocols (e.g. OPC)
- Hardware-in-the-loop (HIL) testing

HiL test system





Virtual Turbine

- HIL test system
  - IPC with real-time model of turbine, “Virtual Turbine”
  - Host PC for test process management (GUI)

Benefits of HiL testing

Reduced engineering effort

- reproducible environmental conditions
- comprehensive testing before commissioning
- save evaluation of behaviour in critical states
- efficient fault analysis – onshore, in the lab

Quality control

- automatic testing of software revisions
- report generation

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Control systems for improved yield, reliability and survivability: tidal energy converters


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