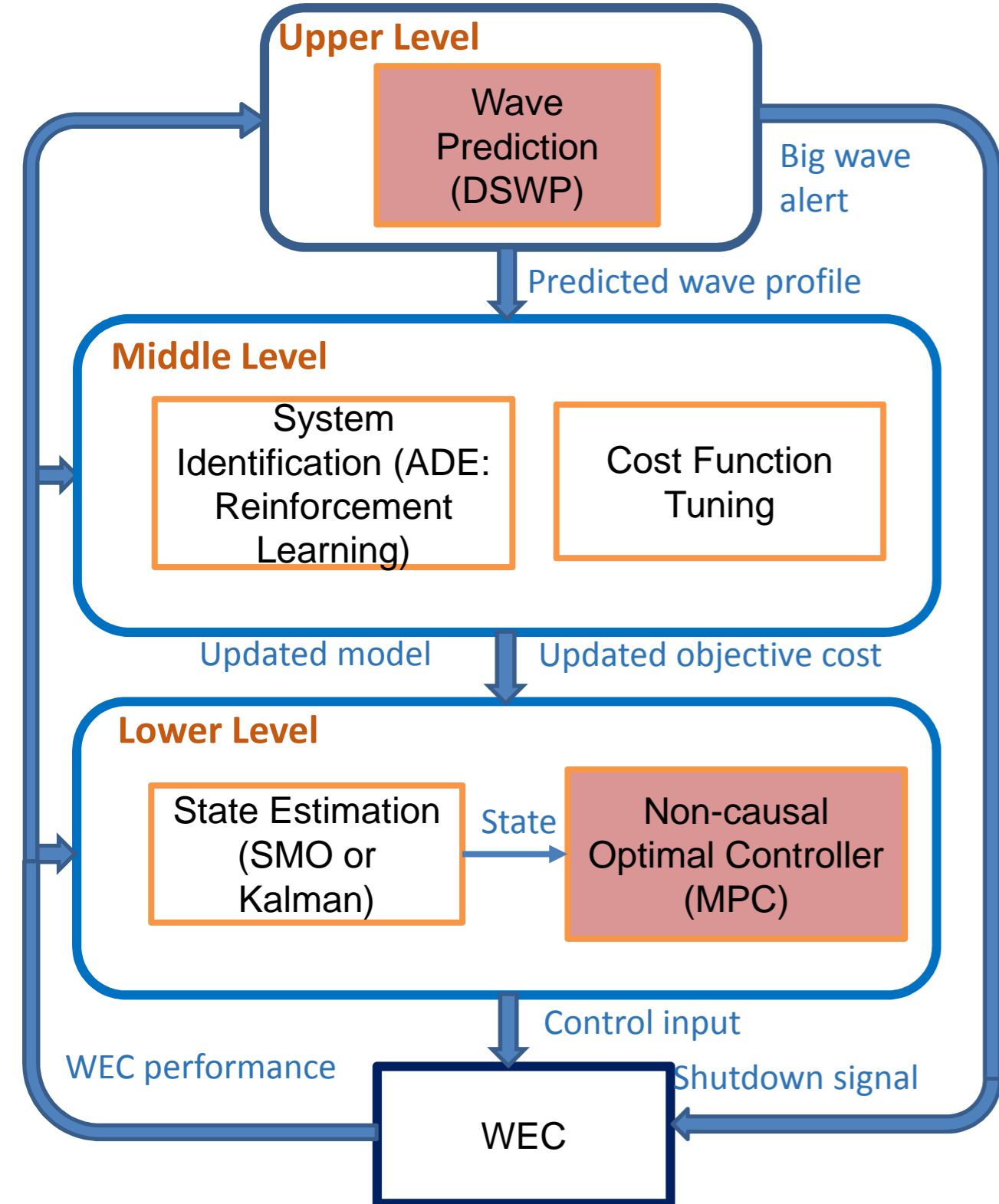


Adaptive Hierarchical Model Predictive Control (AHMPC) of Wave Energy Converters

Our AHMPC framework:



Main benefits:

1. **Maximum energy output** (Direct energy maximisation)
2. **Safe operation** (Constraints satisfactions)
3. **Robustness** (To modelling uncertainties, prediction errors)
4. **Survivability** (Alert of damaging waves)
5. **Universally applicable** (for different types of WECs)

With enabling technologies:

- **Deterministic Sea Wave Prediction (DSWP)**
→ Non-causal optimal control
- **Model Predictive Control (MPC)**
→ Maximum energy output and safe operation
- **Reinforcement learning**
→ Online system identification
- **Sliding mode observer (SMO)**
→ Robust state estimation
- **Quiescent Period Wave Prediction (QPWP)**
→ Alert of damaging waves.

Technology transfers from:

- WES - NWECC programme (Mocean Energy Ltd.)
- EPSRC – [EP/P023002/1](#) (Exeter and QMUL)
- Royal Society – Newton Grant (QMUL)

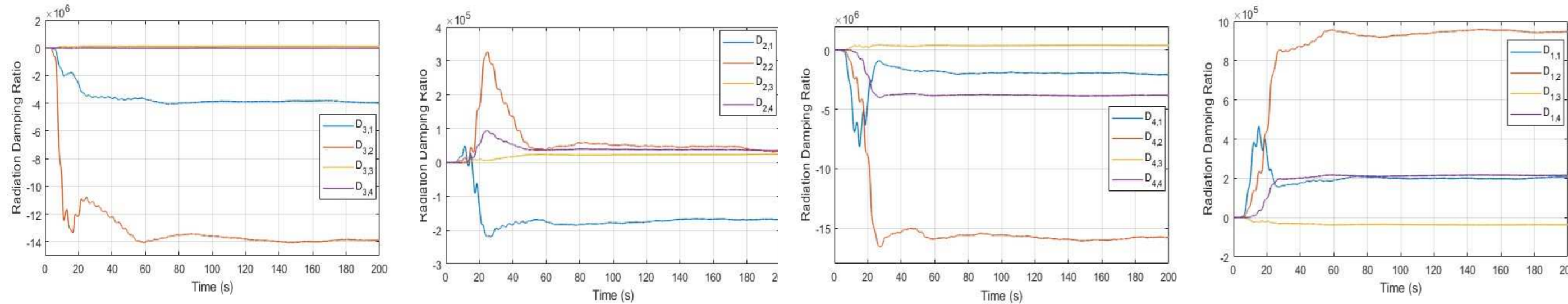
Validation by Mocean M100 WEC



Main features of Mocean M100 WEC:

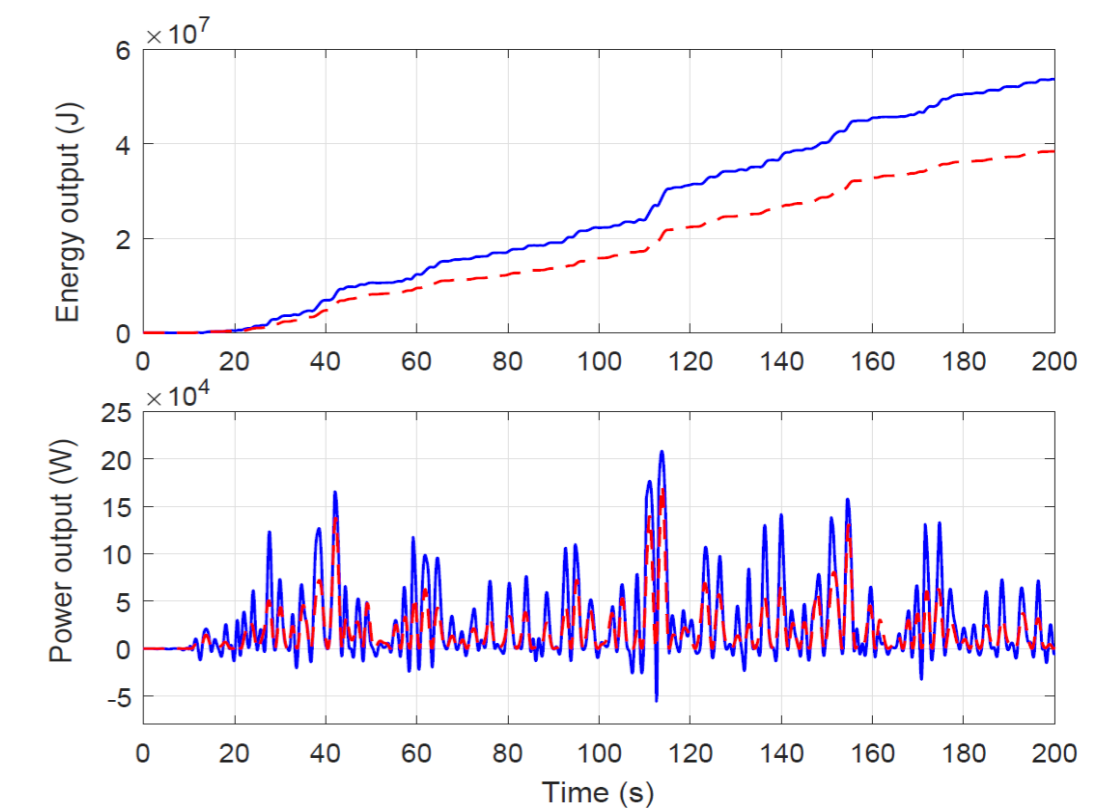
- Multi-float multi-motion attenuator WEC.
- Higher capture width ratio yet more complicated dynamics than point absorbers.
- More challenging controller design problem!

Middle layer dynamics estimator



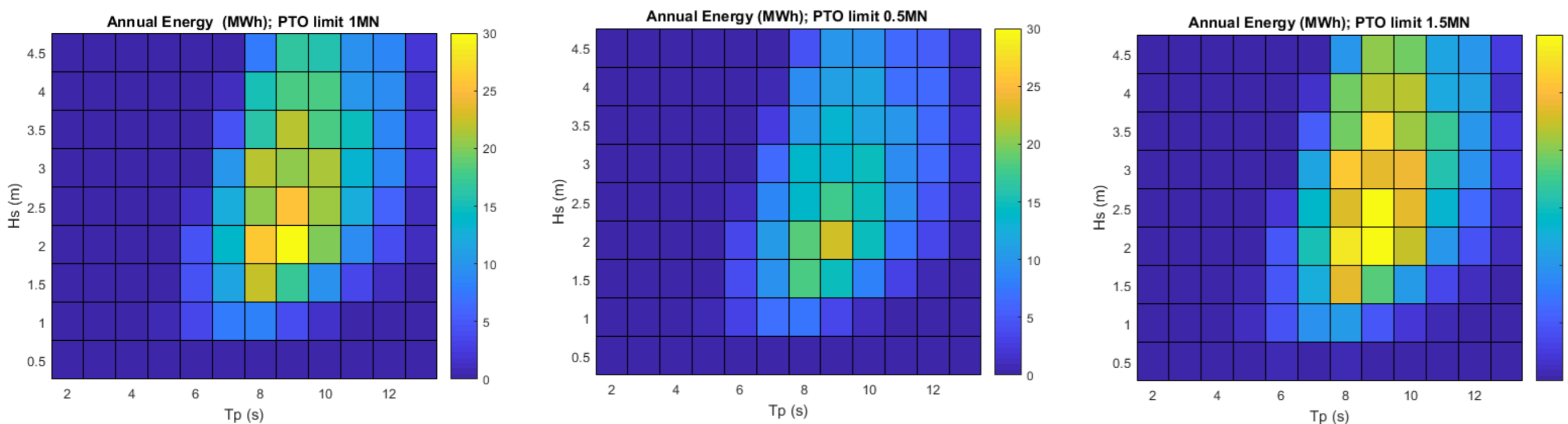
Key dynamics parameters identified by Adaptive Neural Networks converge to accurate values very rapidly.

Bottom layer MPC



AHMPC time domain power and energy output response (blue: AHMPC, red: no controller)

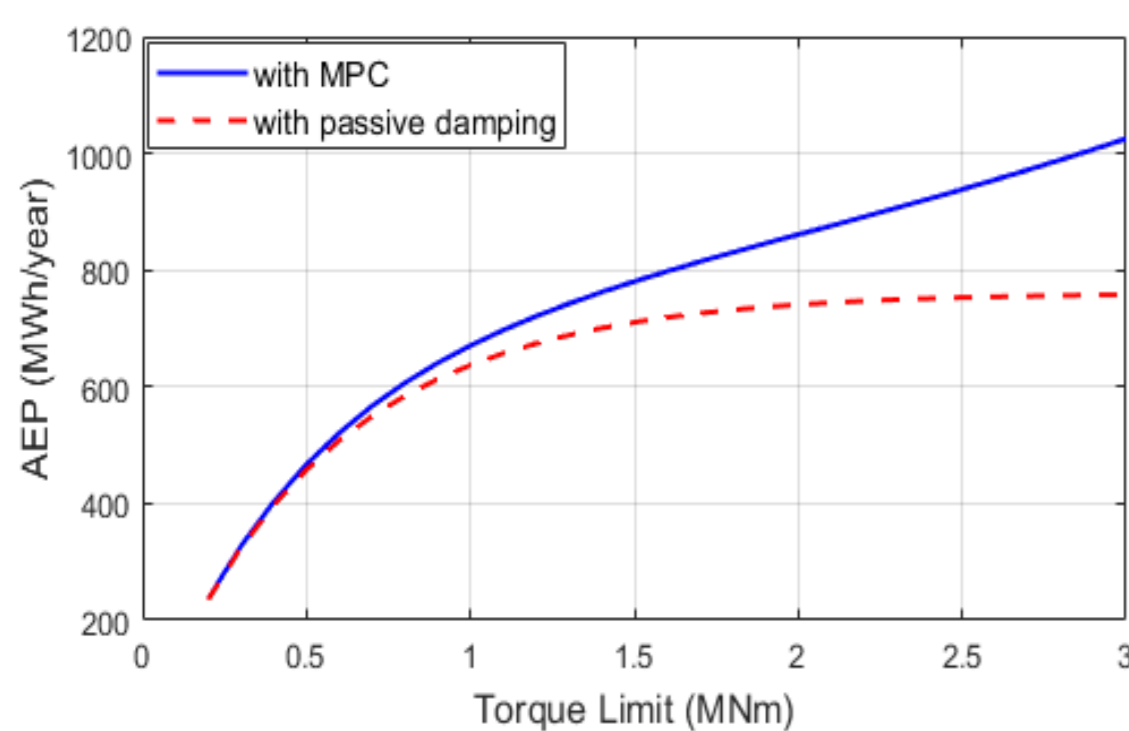
Selected Co-Design Results



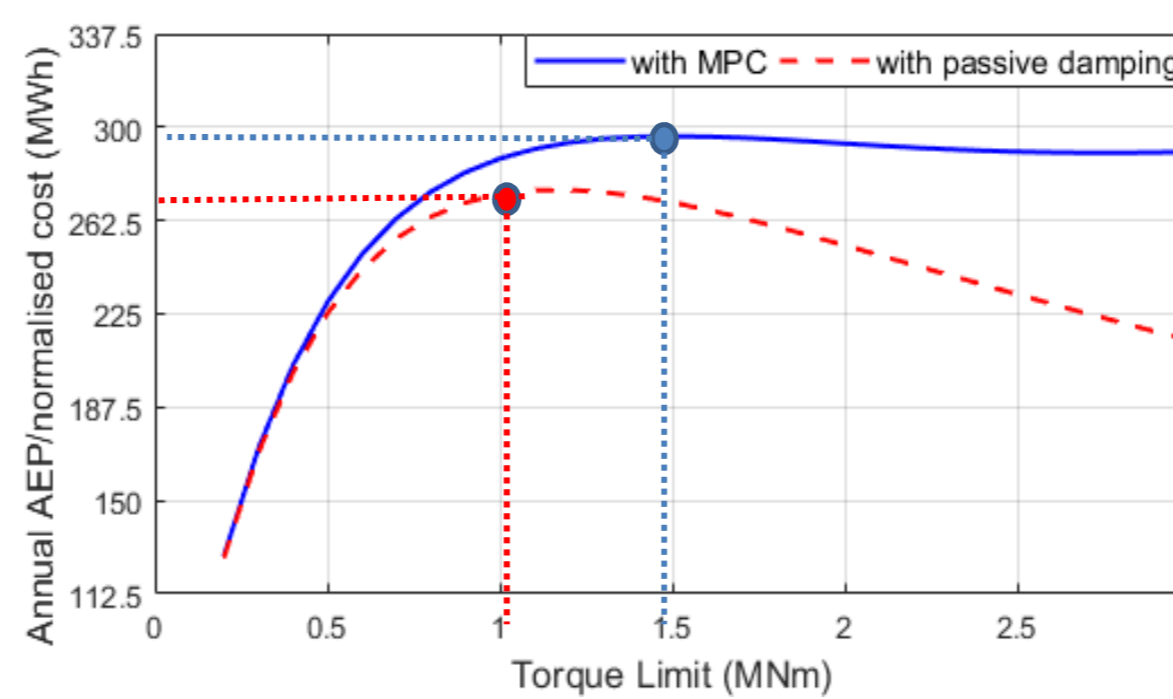
Annual energy production (AEP) matrices with different PTO capacities (Left: 0.5MN; Middle: 1MN; Right: 1.5MN)

| Components | Prime Mover | Moorings/Foundations | Installation | Electrical Connection | Electrical Systems | PTO per MNm |
|-----------------|-------------|----------------------|--------------|-----------------------|--------------------|-------------|
| Normalised Cost | 100% | 50% | 6.7% | 13.3% | 33.3% | 60% |

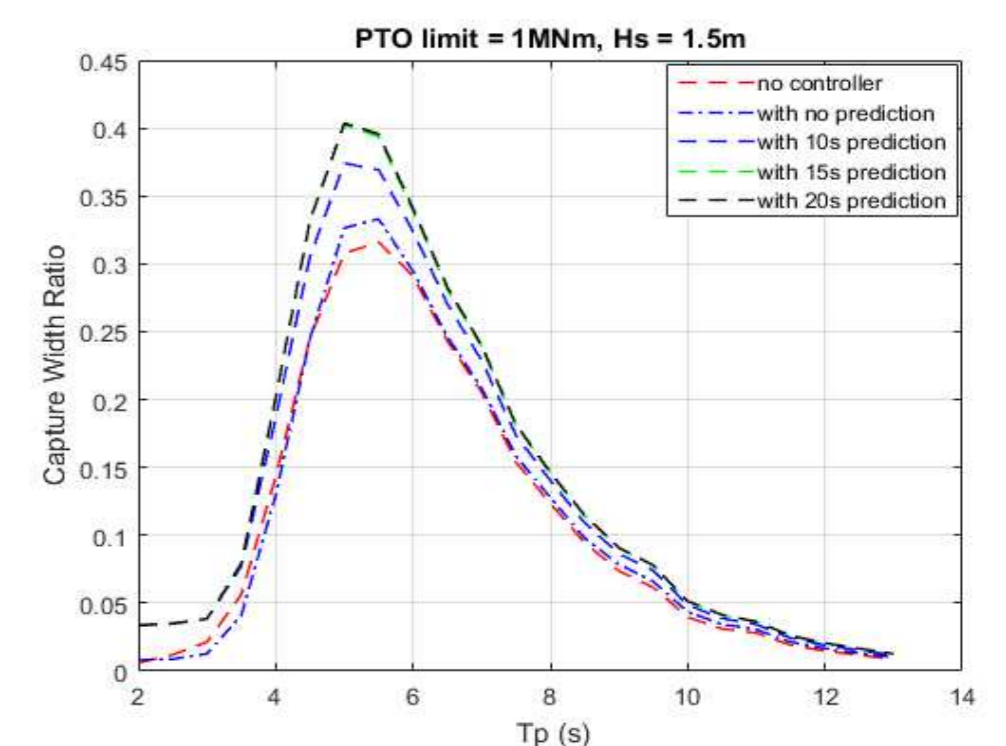
An Example of normalised Cost Breakdown of M100 (with respect to the cost of Prime Mover)



annual energy production (AEP) of MPC with different PTO capacities



annual energy production (AEP) per normalised cost with different PTO capacities (LCOE)



Capture width ratio comparison between with different wave prediction length.

Conclusions:

- Energy conversion efficiency can be significantly improved by up to 90%.
- The annual average unit cost of the co-designed WEC can be reduced by at least 13%.
- Performance is robust to hydrodynamic nonlinearities, uncertainties and prediction errors.
- The techniques are ready to be validated by tank testing.