Intelligent Control for Offshore Wind Energy

Prof Xiaowei Zhao
Supergen ORE Hub – Co-Director
Intelligent Control and Smart Energy (ICSE) Research Group
University of Warwick

Intelligent Control for Offshore Wind Energy

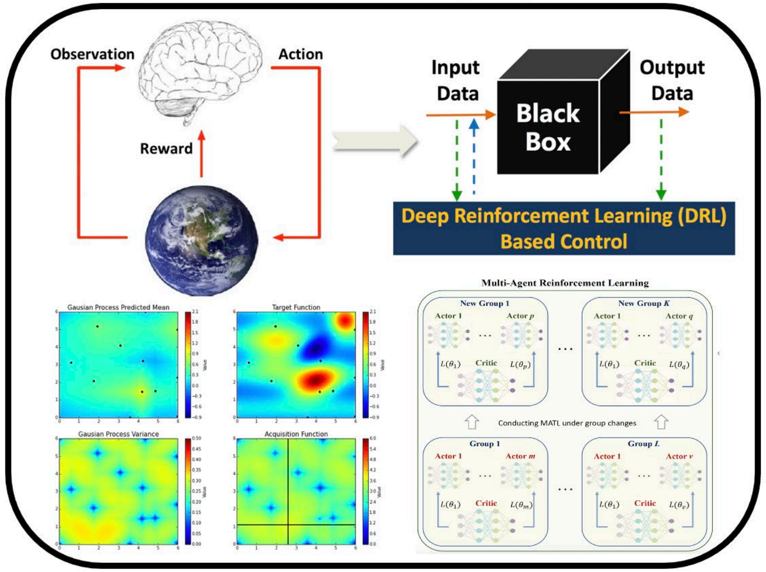
Core Aims

- Developing machine learning tools to provide data-driven innovations for the operation and control of offshore wind energy systems.
- Enhancing operating efficiency, improving economic profitability, and reducing costs.

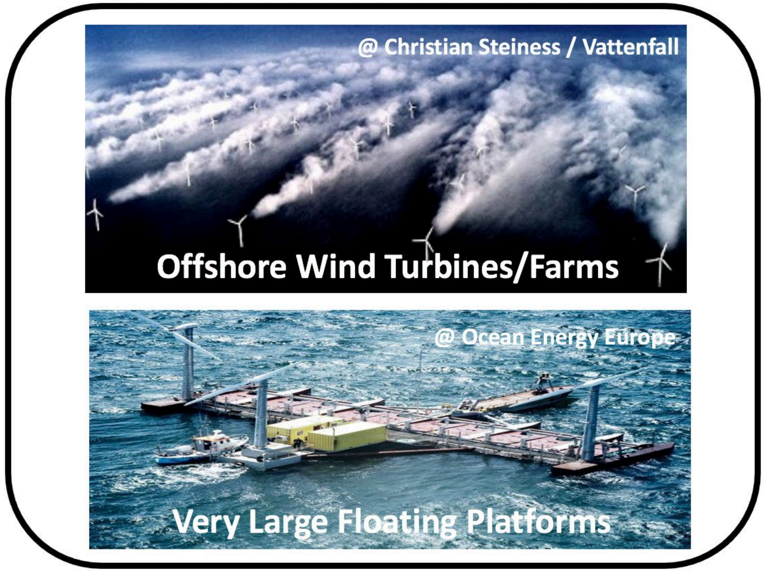
Alignments

- WP5: Floating Futures.
- Theme D: Sensing, Control and Electromechanics.
- Theme F: Operations, Management, Maintenance and Safety.

Machine Learning Tools
(deep reinforcement learning, Bayesian, etc.)



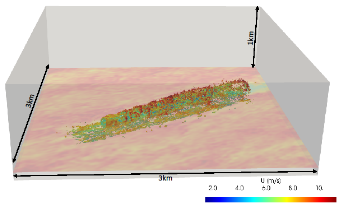
Offshore Wind Systems
(offshore wind turbines/farms, VLFP, etc.)



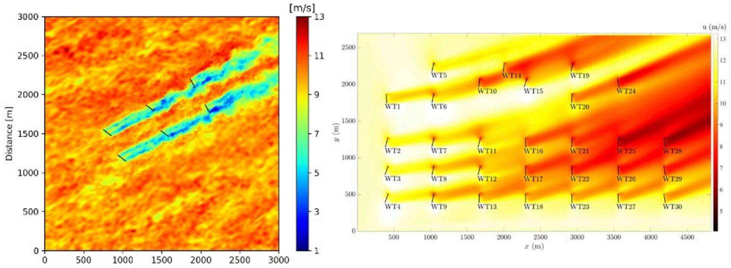
Supergen Offshore Renewable Energy
ICSE Intelligent Control & Smart Energy
WARWICK
UKRI Engineering and Physical Sciences Research Council

Intelligent Wind Farm Control via Deep Reinforcement Learning

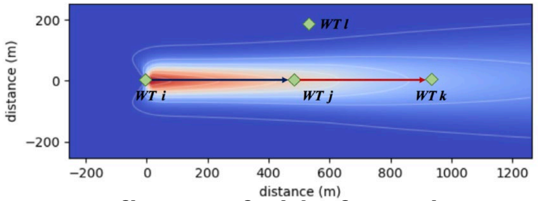
- Optimising long-term, farm-level rewards (e.g., maximising the whole farm's generation).
- Data-driven (only require available measurements) and model-free (no analytical models).



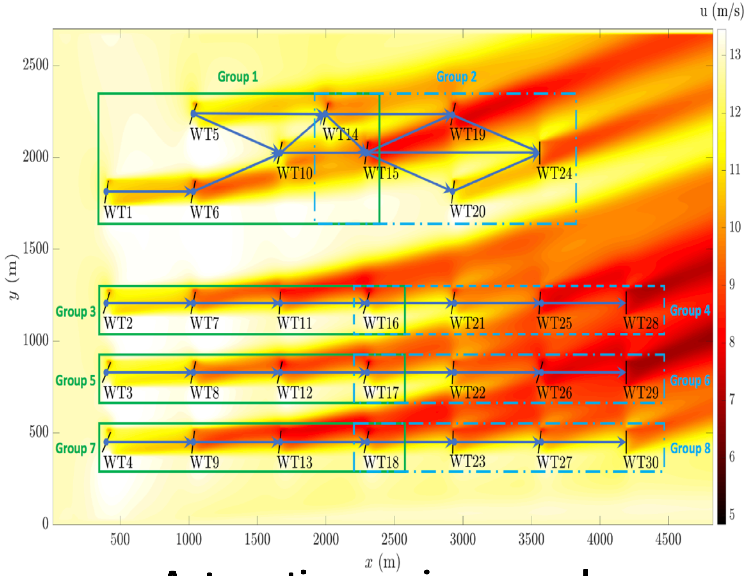
3D simulation

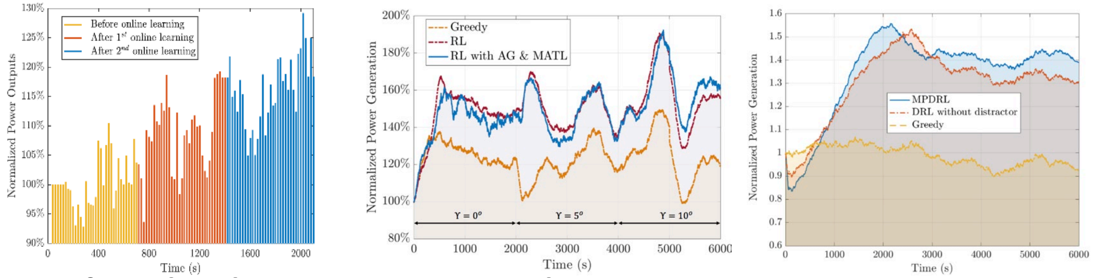


Tests with different simulators

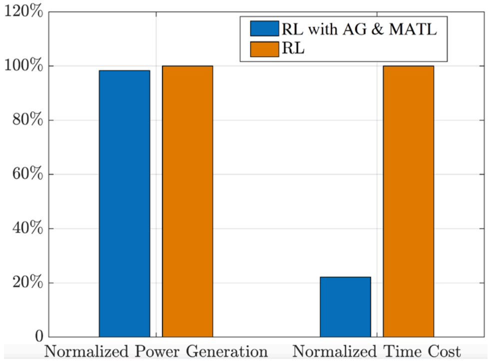


Influence field of a turbine





Better farm-level power generation than mainstream operation strategies



Reduced training time

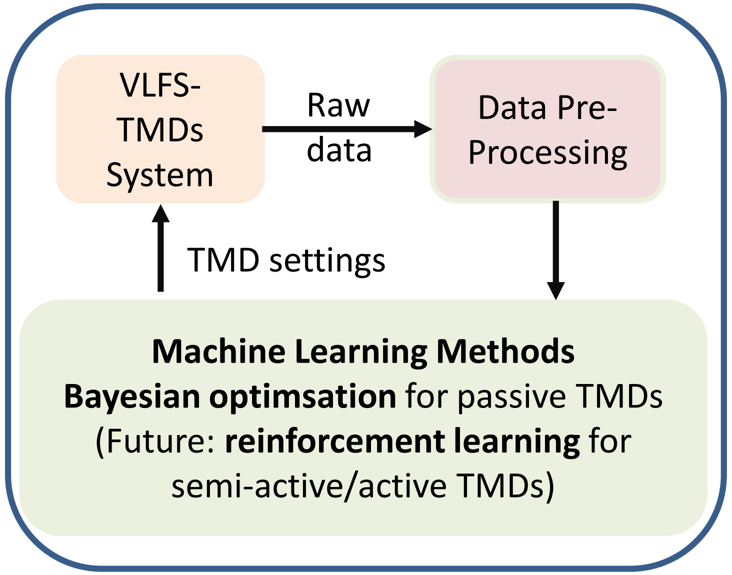
Automatic grouping example

H Dong, X Zhao, Composite Experience Replay-Based Deep Reinforcement Learning with Application in Wind Farm Control, ***IEEE Transactions on Control Systems Technology***, 30, 2022.
H Dong, X Zhao, Wind-Farm Power Tracking via Preview-Based Robust Reinforcement Learning, ***IEEE Transactions on Industrial Informatics***, 18, 2022.
H Dong, J Zhang, X Zhao, Intelligent Wind Farm Control via Deep Reinforcement Learning and High-Fidelity Simulations, ***Applied Energy***, 292, 2021.
J Xie, H Dong, X Zhao, A Karcanias, Wind Farm Power Generation Control Via Double-Network-Based Deep Reinforcement Learning, ***IEEE Transactions on Industrial Informatics***, 18, 2022.
H Dong, J Xie and X Zhao, Wind Farm Control Technologies: From classical control to reinforcement learning. ***Progress in Energy***, 4, 2022.
H Dong and X Zhao, Data-Driven Wind Farm Control via Multi-Player Deep Reinforcement Learning, ***IEEE Transactions on Control Systems Technology***, 2022, under revision.
H Dong and X Zhao, Reinforcement Learning-Based Wind Farm Control: Towards Large Farm Applications via Automatic Grouping and Transfer Learning, ***IEEE Transactions on Industrial Informatics***, 2022, under revision.

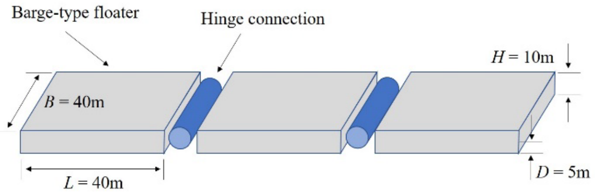
Supergen Offshore Renewable Energy · ICSE Intelligent Control & Smart Energy · WARWICK · UKRI Engineering and Physical Sciences Research Council

Structural Control of Very Large Floating Structures (VLFS)

- VLFS – a promising alternative to traditional floating foundations.
    - “Multiple turbines – one platform” system; One issue in hinged VLFS – structural load/vibration.
- Employing TMDs and machine learning for the structural load/vibration suppression of VLFS.

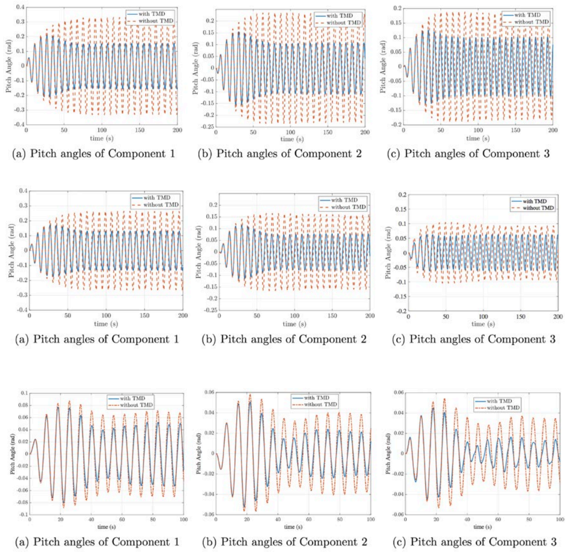


Main design structure

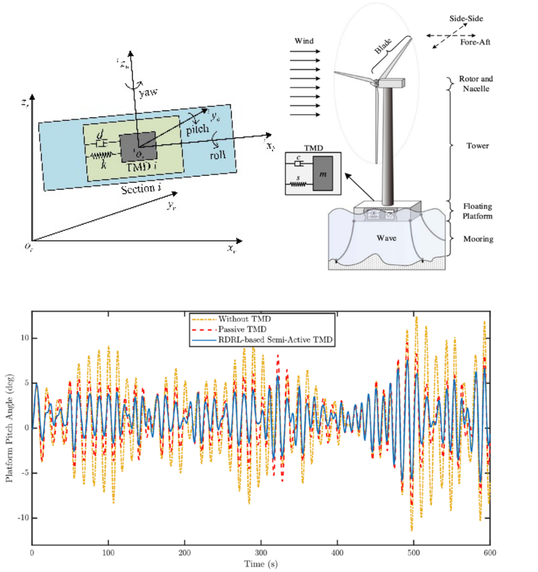


Testing platform

VLFS example illustration



Performance with passive TMDs (Blue: with TMDs; Orange: w/o TMDs)



Performance with semi-active TMDs (for floating wind turbines)

X. Zhang, D. Lu, H. Dong, X. Zhao, F. Brennan, Y. Liang, Vibration Suppression of Multi-Component Floating Structures via Passive TMDs and Bayesian Ascent, ***Ocean Engineering*** 259, 2022.
H. Dong, X. Zhao, and J. Zhang. Robust Deep Reinforcement Learning with Application in Structural Control of Floating Wind Turbines. ***IEEE Transactions on Emerging Topics in Computational Intelligence***, 2022, under revision.

Supergen Offshore Renewable Energy
ICSE Intelligent Control & Smart Energy
WARWICK
UKRI Engineering and Physical Sciences Research Council

Work in other WPs and cross-hub collaborations

Work package 3 (modelling):

Wind farm wake modelling based on machine learning

- R. Li, J. Zhang, X. Zhao, Multi-fidelity modeling of wind farm wakes based on a novel super-fidelity network, ***Energy Conversion and Management*** 270, 2022.
- R. Li, J. Zhang, X. Zhao, Dynamic Wind Farm Wake Modeling Based on a Bilateral Convolutional Neural Network and High-Fidelity LES Data, ***Energy*** 258, 2022.
- J. Zhang and X. Zhao, Wind farm wake modeling based on deep convolutional conditional generative adversarial network, ***Energy*** 238, 2022.

Work package 4 (design):

Wind and wave prediction based on deep learning

- J. Zhang, X. Zhao, S. Jin, and D. Greaves, Phase-resolved real-time ocean wave prediction with quantified uncertainty based on variational Bayesian machine learning, ***Applied Energy*** 324, 2022.
- J. Zhang and X. Zhao, Three-dimensional spatiotemporal wind field reconstruction based on physics-informed deep learning, ***Applied Energy*** 300, 2021.

Cross-hub collaborations with three other supergen hubs/network+:

- M. Kheshti, X. Zhao, T. Liang, B. Nie, Y. Ding, and D. Greaves, Liquid Air Energy Storage for Ancillary Services in an Integrated Hybrid Renewable System, ***Renewable Energy*** 199, 2022
- M. Kheshti, S. Lin, X. Zhao, L. Ding, M. Yin, and V. Terzija, Gaussian Distribution-Based Inertial Control of Wind Turbine Generators for Fast Frequency Response in Low Inertia Systems, ***IEEE Transactions on Sustainable Energy*** 13, 2022
- **EPSRC project** (Jan 2022 – Jan 2025) - High efficiency reversible solid oxide cells for the integration of offshore renewable energy using hydrogen.

Thank you for your attention.

Prof Xiaowei Zhao
Supergen ORE Hub – Co-Director
Intelligent Control and Smart Energy (ICSE) Research Group
University of Warwick