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# Connecting Wind Power to Electrolysers – Control for an Offshore and Off-Grid Approach

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## Why Offshore and Why Off-Grid?

Offshore and off-grid production of hydrogen from wind energy is attractive for several reasons:

- There is greater wind resource available offshore [1] and the public hold significant preferences for offshore wind power over on-land developments [2]
- Once offshore, cost analyses show that offshore, off-grid methods may be lower cost than grid connected options, as the savings through reduced grid components (~15% of the cost of the grid-connected option) are greater than the increased system costs associated with offshore electrolysis.

Whilst the difference in costs between on and off-grid options is small, and there is significant uncertainty in estimates, there is a clear case for further research into how best to operate offshore, off-grid wind to hydrogen systems.

However, producing hydrogen offshore and off-grid does introduce challenges, many of which can be addressed through control engineering.

## Accronyms

PEM - Proton Exchange Membrane
LCOH - Levelised Cost of Hydrogen
NC - No Control
WFC - Wind Farm Control
SC - Supervisory Control
PAC - Power Adjusting Controller
EETF - Emerging Technologies Fund

## Thanks

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## Centralised or Decentralised Approach

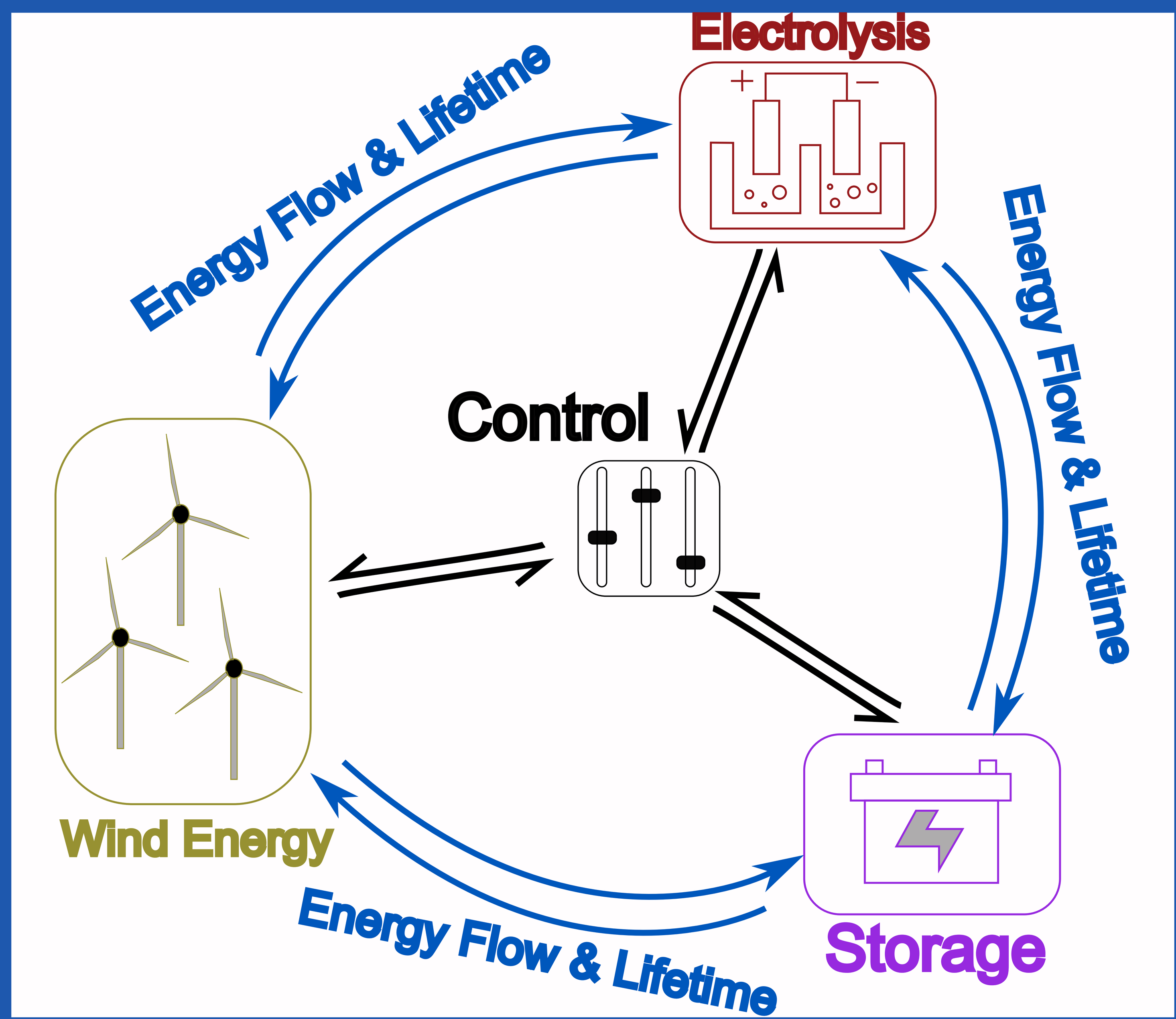
Some wind turbine manufacturers are pursuing a **decentralised** approach to creating green hydrogen wind farms, in which each wind turbine is coupled to a single electrolyser. An alternative approach is a **centralised** configuration, with a central pool of electrolyser connected to the power flow from the whole wind farm.

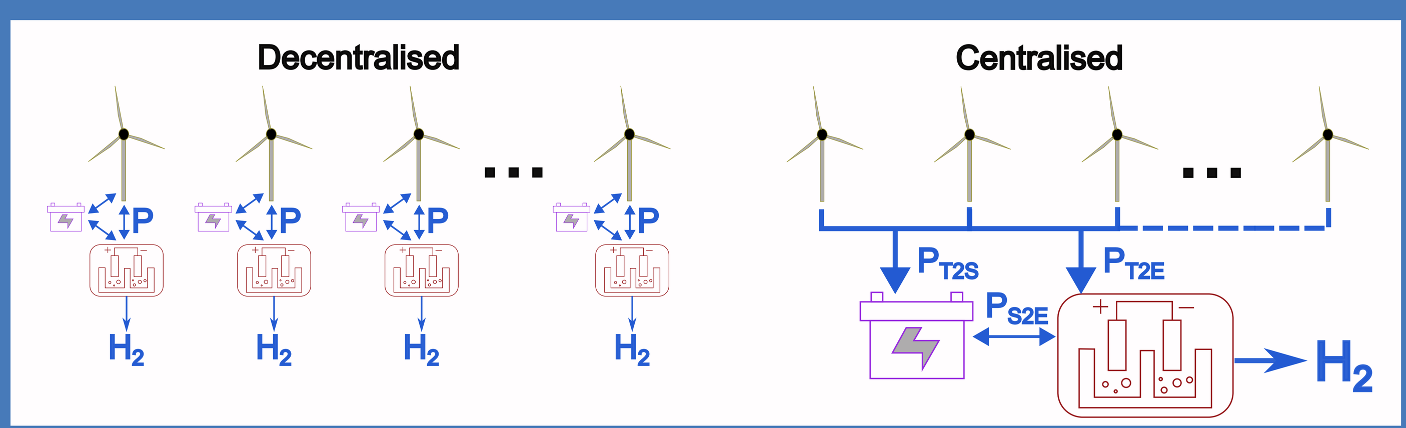
Whilst a decentralised approach has some advantages (e.g. no power cable interconnection between turbines, a more modular design), a centralised approach has greater potential to, through control, reduce the power variations through the system, as wind farm control approaches can be utilised that give much greater flexibility in control.

Reducing the power variations can reduce the size and cost of batteries, and prolong electrolyser lifetime through intelligent scheduling.

Recent studies estimate that offshore, off-grid options may be cheaper for future hydrogen production than on-grid solutions [1], and so the work presented here focuses on off-grid topologies.

Beyond the smoothing of power from the wind turbines, there are also numerous control challenges in ensuring that off grid electrolysers are operated in an efficient manner to minimise cyclic loads and the number of start-ups and shutdowns




## Technological Challenges of Offshore and Off-Grid Electrolysis

### Challenge 1: The Electrolysers

- Electrolysers prefer steady power inputs as, whilst some (e.g. PEM) can vary their demand, variations in power increase damage cycles, increasing failures and reducing component lifetime
- Powering electrolysers up and shutting them down is time consuming and can be damaging for the electrolyser and so should be minimised
- Electrolysis requires desalinated water, so additional infrastructure, that may also require power, must be provided
- Once produced, hydrogen must be either stored or exported, requiring either storage capacity or export pipes plus compressors etc.

### Challenge 2: The Turbines

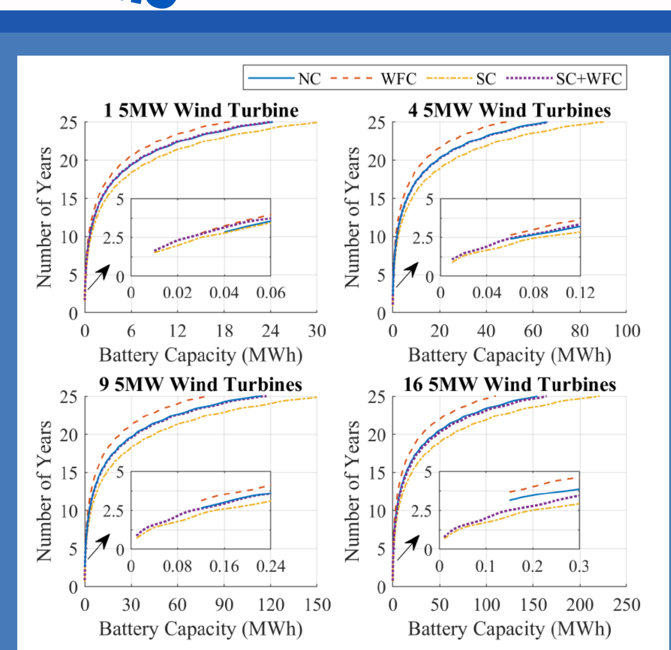
- Wind turbines typically provide highly variable power output. Whilst larger wind farms have lower variability in power it is still significant
- Wind turbines provide intermittent power - in low wind no power is provided at all
- The cost of running the wind turbines directly impacts the LCOH, so turbines must be operated in a manner that balances operational loads, total energy production and power variability
- The control and operation of the turbine could be significantly different from usual, as could the fundamental design of the turbine

### Challenge 3: The Storage

- Storage is almost certainly required for electricity and may be required for hydrogen as well
- Larger electrical storage is more expensive to install but provides facility to smooth power and provide energy in low wind conditions

## Work Completed So Far

### Power Smoothing impact on Battery Sizing [2]



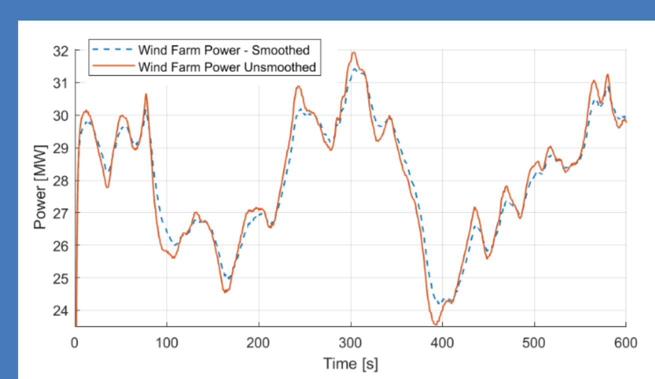

The variation in power flow from wind turbines can have a deleterious effect on the lifetime of the electrical storage, as the more charge and discharge cycles the storage goes through the greater the fatigue loads on the component.

**SIMULATION SETUP**

- Proof of concept of a WFC approach to smoothing wind farm power output
- Electrolyser model provides realistic capability for power demand variation
- Wind farm model including wakes and turbulent wind provides the power input
- Lithium-ion battery lifetime model used to calculate the impact of fulfilling the required difference in power
- WFC approach assumed to work well to smooth power (keeping within physical limits)

**SIZE OF WIND FARM MATTERS**

For batteries with an expected lifetime of **15 years**, the WFC-based average battery capacity per 5 MW wind turbine is **decreased by around 65%** from 17 MWh to 6 MWh when the wind farm scale increases from 1 × 5 MW wind turbine to 16 × 5 MW wind turbines




Time plot of smoothing for wind farm

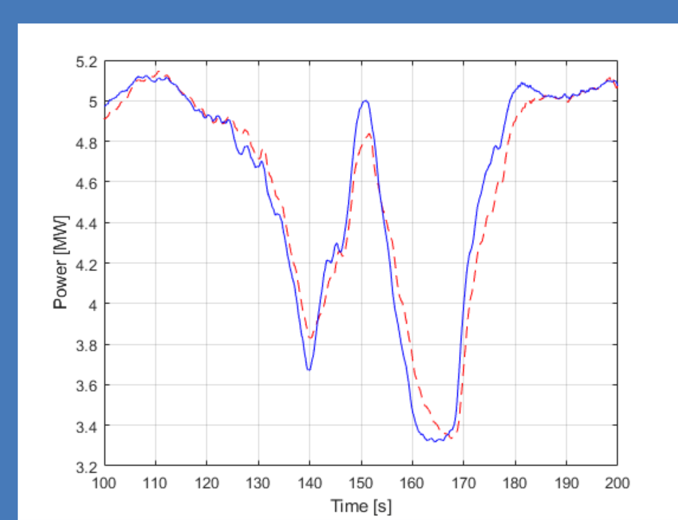
**WIND FARM CONTROL CAN HELP FURTHER**

WFC can further smooth the power of wind farms to facilitate direct electrolysis of hydrogen, increasing battery lifetime for a given battery size and hence facilitating the use of smaller, less costly batteries. For example, for a wind farm of 16 × 5 MW wind turbines, batteries with a lifetime of 15 years (which require one replacement over a typical 25-year wind farm lifetime with some safety margin) have approximately a 30% reduction in required capacity (reduced from from 140 MWh to 100 MWh)

**FEASIBILITY OF TURBINE LEVEL CONTROL**

To smooth the wind farm power, individual turbines require adjustments to their power output. This can be done using a controller augmentation called the PAC.

Ongoing work is demonstrating the PAC in use for the OREC LDT turbine. Control implementations for smoothing a single turbine's power (without a wind farm) are being developed to facilitate decentralised off-grid electrolysis




Time plot of smoothing for single wind turbine

## Future Work

Current work is ongoing through the Scottish Government funded EETF scheme, however, funding has also recently been awarded to build further in this area through the UKRI, Innovate Network Plus, "Researcher in Residence" (RiR) Scheme

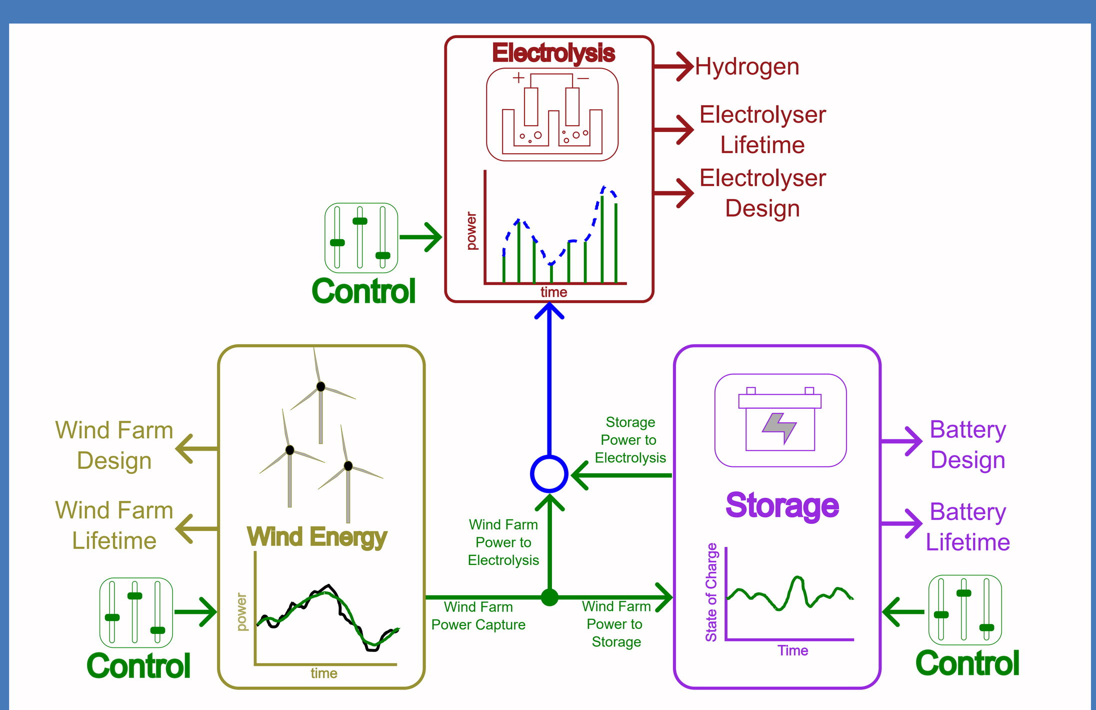
The research objectives of the RiR project are as follows:

1. To combine and extend existing models of system components to create a baseline green hydrogen plant model capable of evaluating the role control can play in improving the performance.

2. To create suitable controller architectures and controller design work-flows across the green hydrogen system in order to facilitate control implementation throughout the system

3. To implement control methods throughout the system to demonstrate measurable improvement in LCOH from green hydrogen systems.

The RiR will develop the tools and the initial control approaches that will help wind to hydrogen systems become a reality. Controllers will be implemented for all systems, as shown in the diagram below.




Throughout and beyond the project, the engagement with industry and other academics will not be a "closed house". Through collaboration with the IEA wind task 50 on hybrid systems, the outputs of the project will be shared internationally with a wide range of stakeholders. If you are interested in collaboration then please find me at the conference for a discussion.

It is hoped that the tools developed will facilitate other researchers in contributing to this growing research area, enabling wind energy to further contribute to international Net Zero goals

## References


[1] Troen, I. E. L. P., and Erik Lundtang Petersen. "European wind atlas." (1989).
[2] Ladenburg, Jacob. "Stated public preferences for on-land and offshore wind power generation—a review." Wind Energy: An International Journal for Progress and Applications in Wind Power Conversion Technology 12.2 (2009): 171-181.
[3] Spyroudi, Angeliki, et al. "Offshore wind and hydrogen: solving the integration challenge." (2020).
[4] Stock, Adam, et al. "Wind farm control for improved battery lifetime in green hydrogen systems without a grid connection." Energies 16.13 (2023): 5181.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