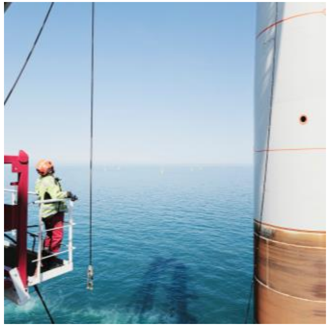
Wind Power Plant Capabilities and Trials



Wind Power Work Package

Control Specialist - Mikkel Gryning

Agenda

Role

Why is wind useful for frequency support?

Now

Current capabilities

Trials

Prove the capabilities

Desired

Future capabilities

Trials

Prove capabilities

Commercial

Develop and shape the frequency response market.

Challenges?

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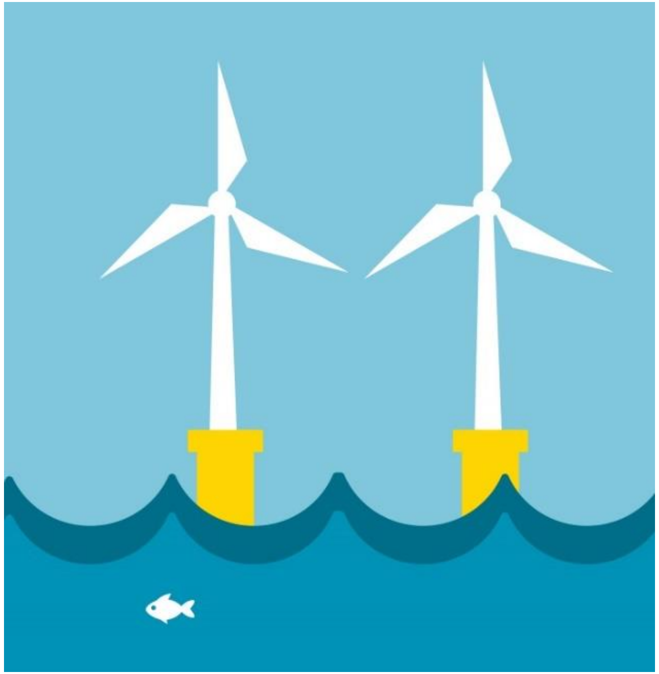
Role – why wind?

- **7.5 GW** installed across generators (UK).
  - Estimated **25 GW** by 2025 globally.
- CAPEX and OPEX have **dropped significantly.**
- **Subsidies** are at a record low (75£/MWh).
- Connection point at **remote locations.**
- Technology supports **fast response**
- Complex control system **already in place**
  - Local control and wide area control
  - Supports most available interface protocols



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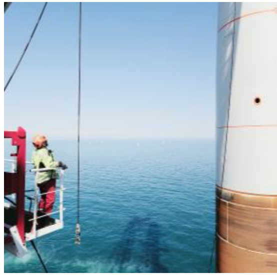

Current capabilities – proportional frequency response.

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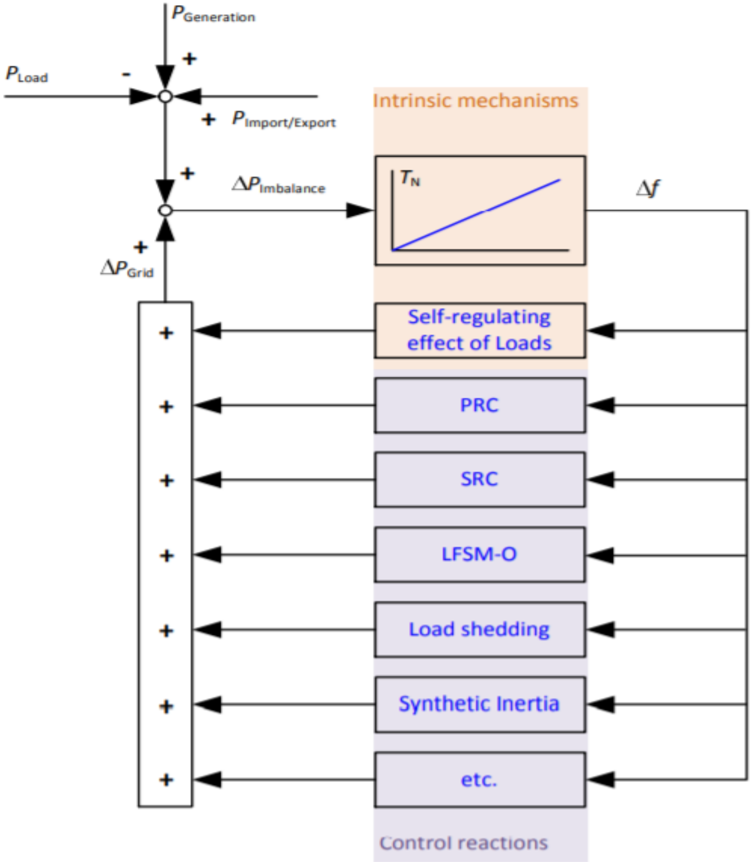
Current control reactions

- ENTSO-E (L)FSM O & U, FSM
  - Primary Response (PRC)
  - Secondary Response (SRC)
  - High Frequency Response (HFR)
- – Response droops of 1%-20%.
- Synthetic/Virtual Inertia supported by many turbine manufactures
- Tripping schemes
- – Shedding and de-load functions.



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Trial at Burbo Bank Wind Farm

- 90 MW installed capacity
  - **25 SGRE-3.6 MW** turbines close to Liverpool Bay.
  - Supports **proportional control**

Number	Mode	Droop	Deadband (Hz)	Injection
1	FSM	3.3333	0.015	-
2	FSM	3.3333	0.015	-
3	FSM	1.0000	0.015	-
4	FSM	20.0000	0.015	-
5	FSM	3.3333	0.100	-
6	FSM	3.3333	0.200	-
			0.300	-
			0.400	-
7	FSM	3.3333	0.015	49.50 Hz
8	FSM	3.3333	0.015	50.50 Hz
9	N/A	N/A	N/A	0 MW

Table 5 – BBW01 Tests

- Why?
  - Settings outside required
  - Show limitations of stochastic resources
  - Identify asset impact, cost and OPEX changes.

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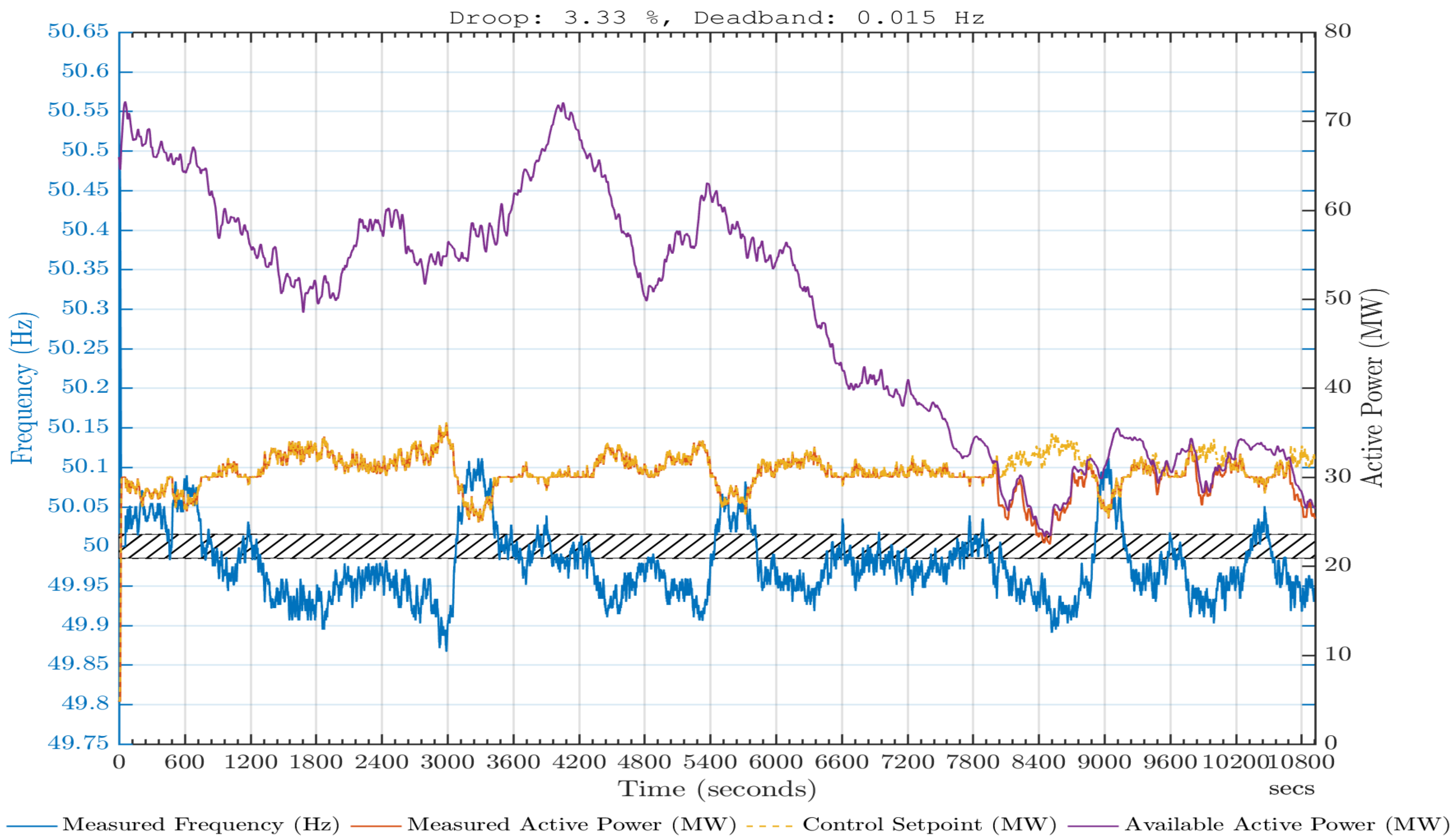
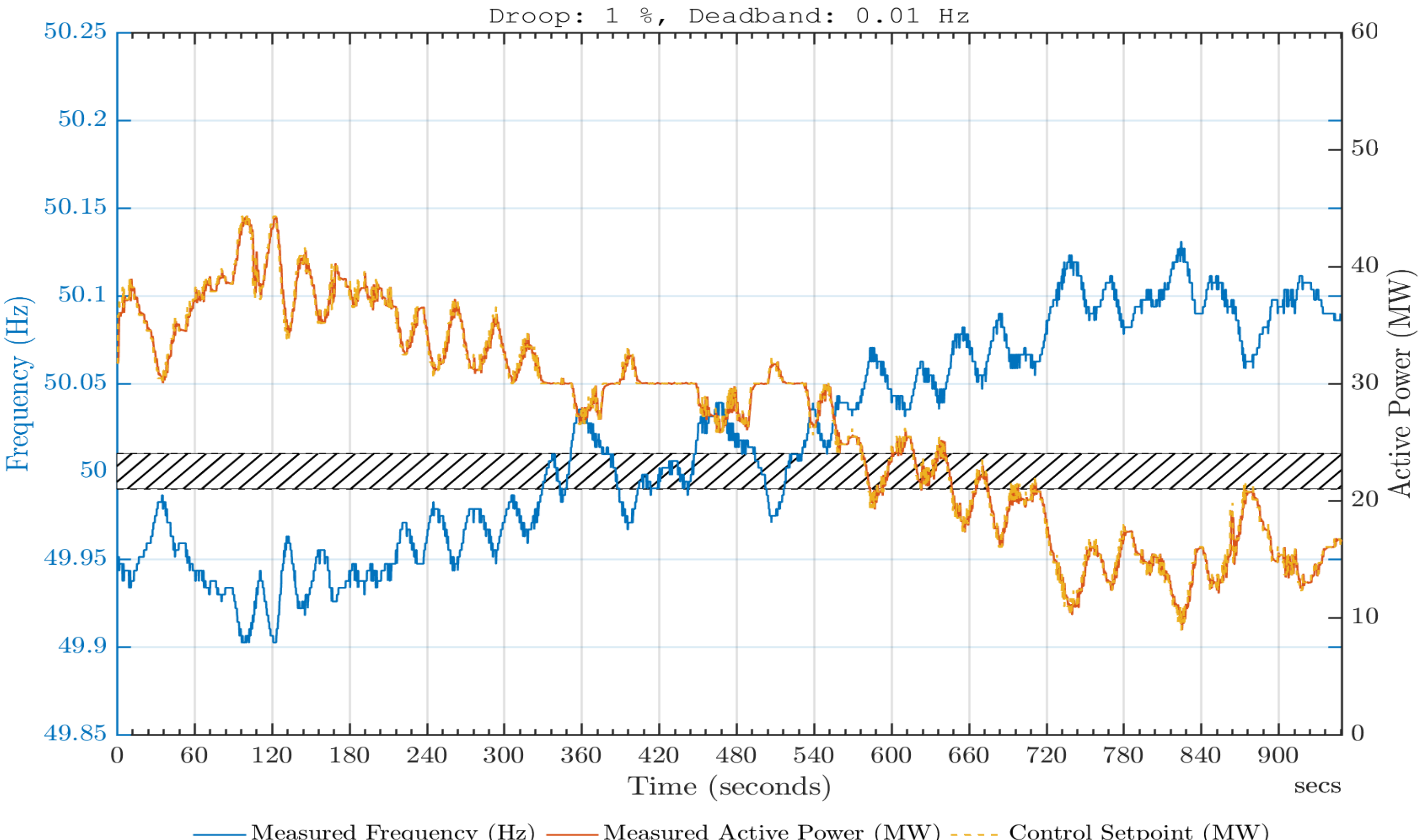


Droop: 3.33 %, Deadband: 0.015 Hz
Frequency (Hz)
Active Power (MW)
Time (seconds)
secs
50.65
50.6
50.55
50.5
50.45
50.4
50.35
50.3
50.25
50.2
50.15
50.1
50.05
50
49.95
49.9
49.85
49.8
49.75
80
70
60
50
40
30
20
10
0
0
600
1200
1800
2400
3000
3600
4200
4800
5400
6000
6600
7200
7800
8400
9000
9600
10200
10800
Measured Frequency (Hz)
Measured Active Power (MW)
Control Setpoint (MW)
Available Active Power (MW)


Droop: 1 %, Deadband: 0.01 Hz
Frequency (Hz)
50.25
50.2
50.15
50.1
50.05
50
49.95
49.9
49.85
Active Power (MW)
60
50
40
30
20
10
0
0
60
120
180
240
300
360
420
480
540
600
660
720
780
840
900
Time (seconds)
secs
Measured Frequency (Hz)
Measured Active Power (MW)
Control Setpoint (MW)

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Results

- Compliance with current grid code requirements and more.
- Sub second response times – 150ms to 1000ms.
  - Downregulation 0.2 pu/s, upregulation 0.1 pu/s for 40% of rated power and 0.05 pu/s of the remaining capacity.
- Droop of 1% or less combined with a small dead band was promising for fast acting proportional frequency support.
- Droops lower than 1% can have a small impact on asset integrity due to frequent and high magnitude activation.

No curtailment no upward response, no wind - no response at all.

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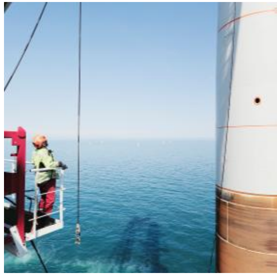
Wind Power



New capabilities – df/dt minimization

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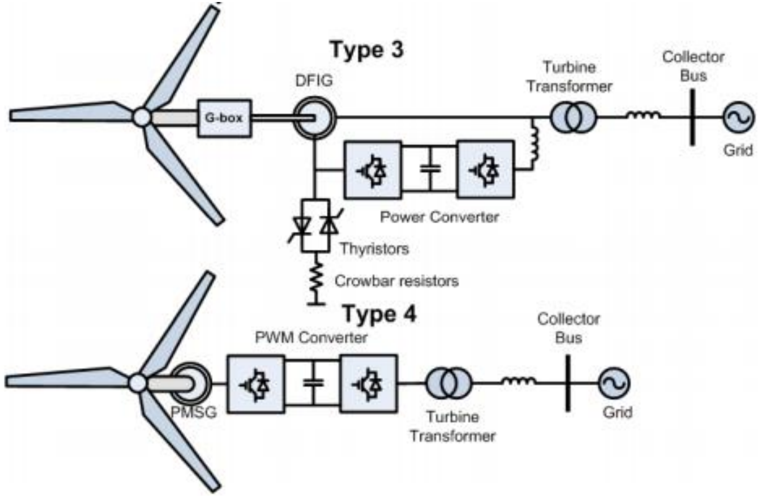
New capabilities – df/dt minimization.

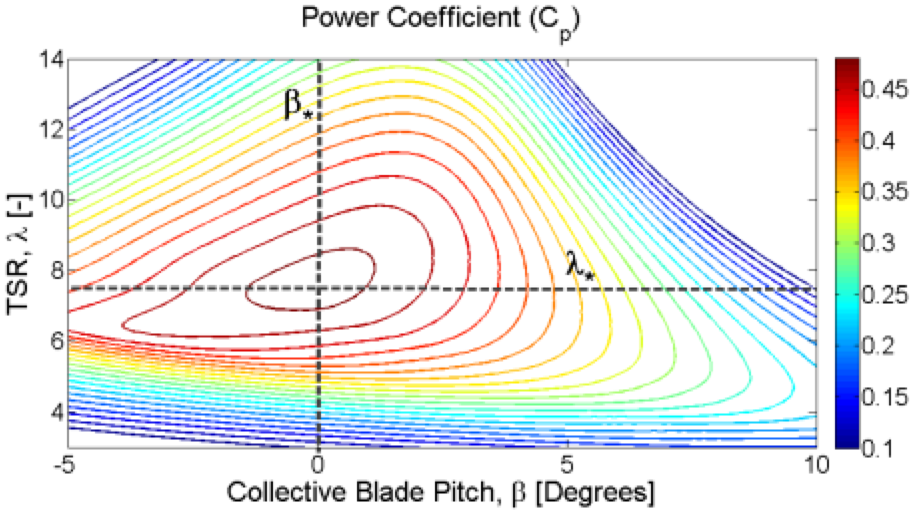
- **Problem**: Existing capabilities are limited by the available wind resource
- **Solution**: Use energy stored in the mechanical parts of the system for a short burst of additional energy.
  - Inertial Response (IR) functionality.
  - Not virtual inertia.

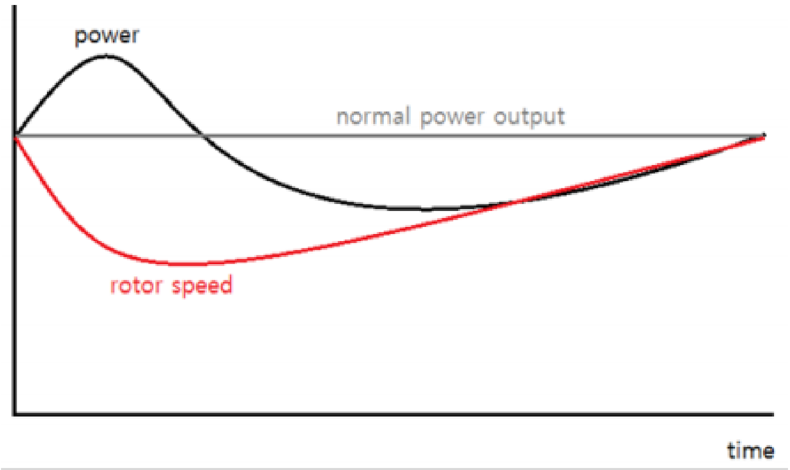


- High level governing equations
  - $\Delta E = \frac{J}{2}(\omega_0^2 - \omega_1^2)$
  - $\Delta P = \Delta E / \Delta t$
  - $\dot{\omega_r} = \frac{1}{J}(T_a - T_e)$

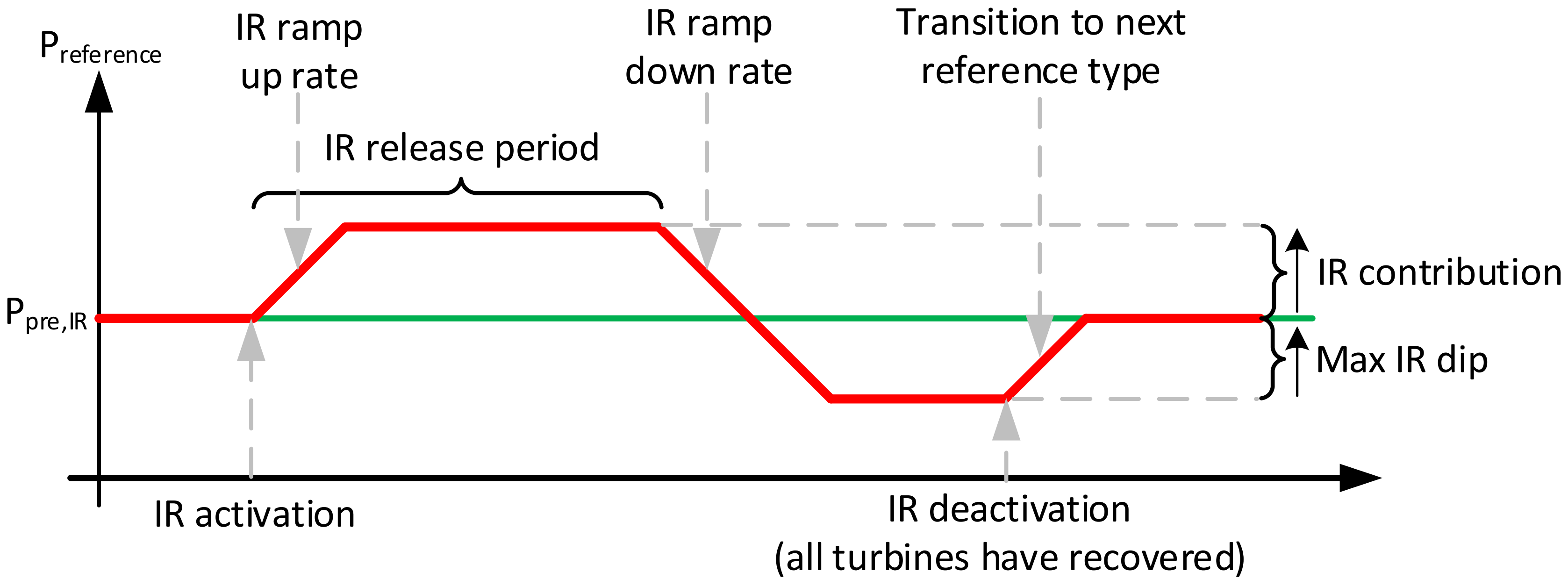
Consequences

- Aerodynamic torque (T_a) is governed by a power coefficient $C_p(\beta, \lambda)$ – the collective blade pitch and the tangential speed of the blade tips relative to the wind speed, and has an optimal operating point.
- Generator torque (T_e) is directly controlled by increasing output current.





Response profile



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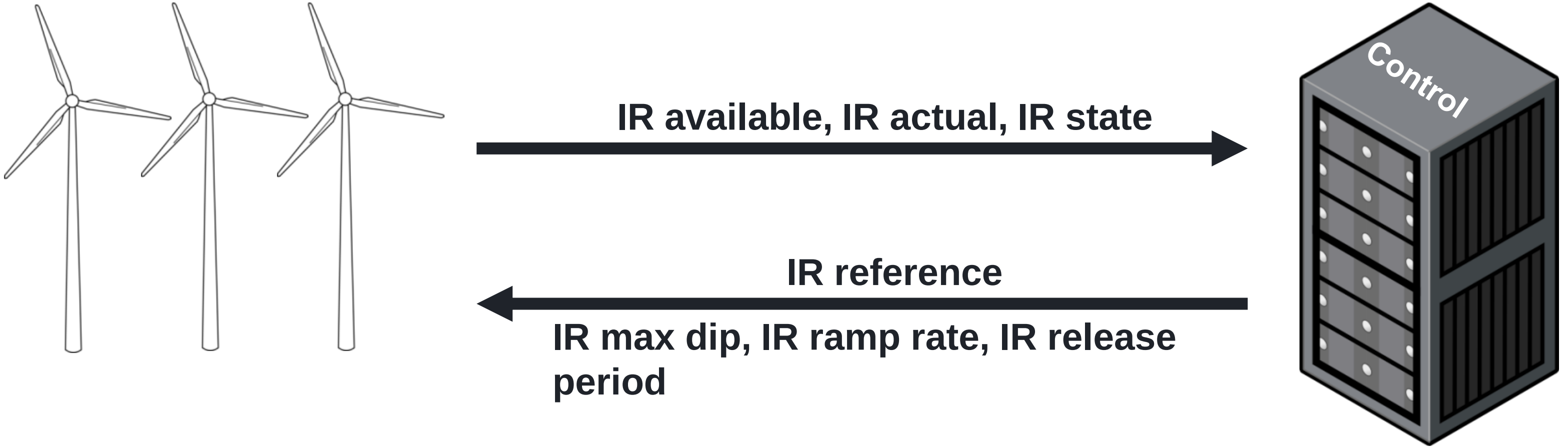
Implementation (Extended IR)



IR control
The requested IR will be delivered at the point of common coupling using closed loop control.

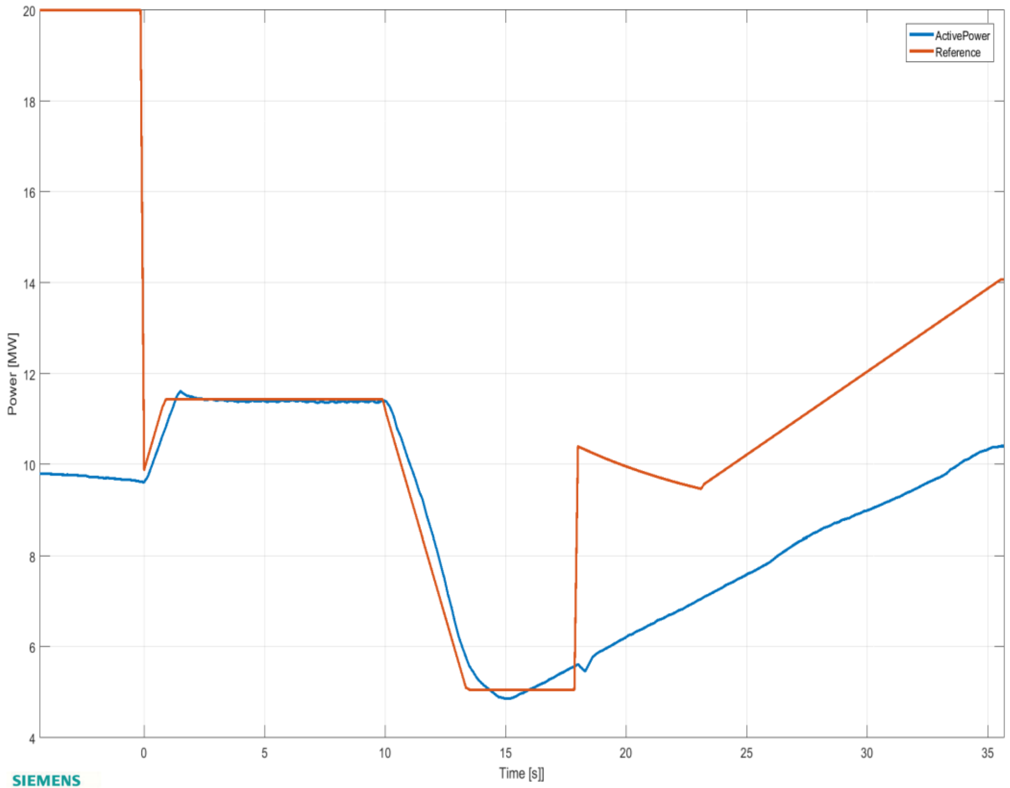
IR reference dispatching
The HPPP dispatches the IR references based on the available IR from each individual turbine. Turbines with more IR available will contribute with most of the response.

If a turbine goes out of IR scope, the HPPP will use the other turbines to compensate.

Single Turbine Test – Part One

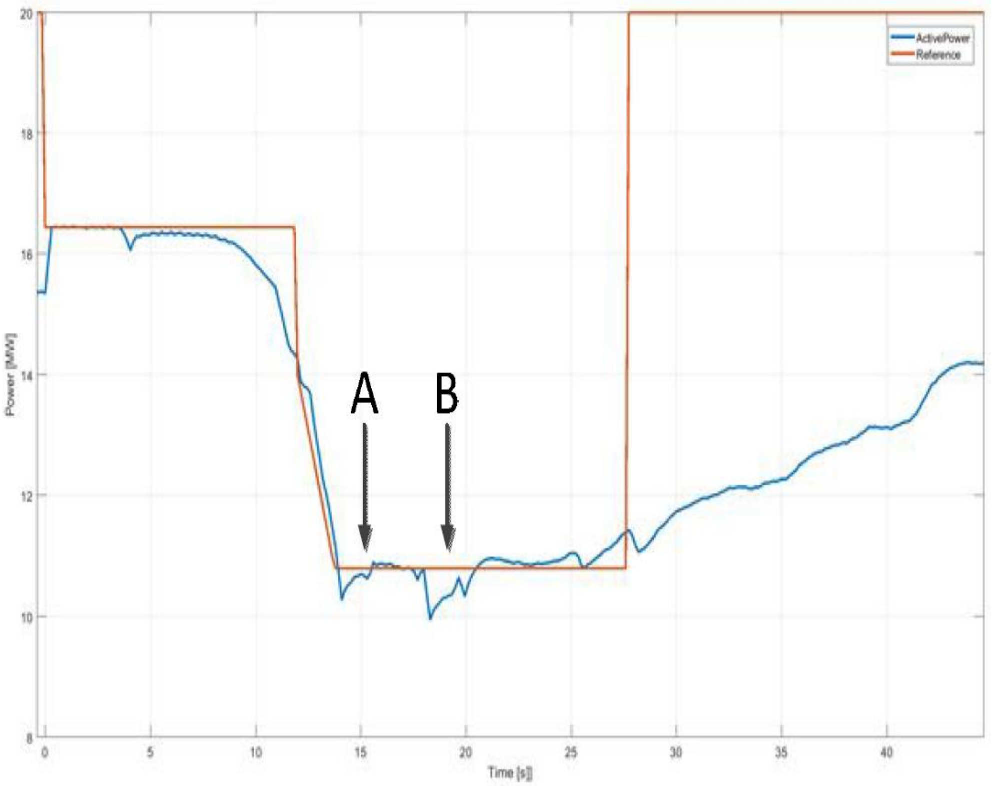
- 10 % power for 10 seconds.
- 25 % recovery drop.

- Reference is tracked during injection
- Turbines allowed to increase in recovery.
- Fully coordinated by park controller.

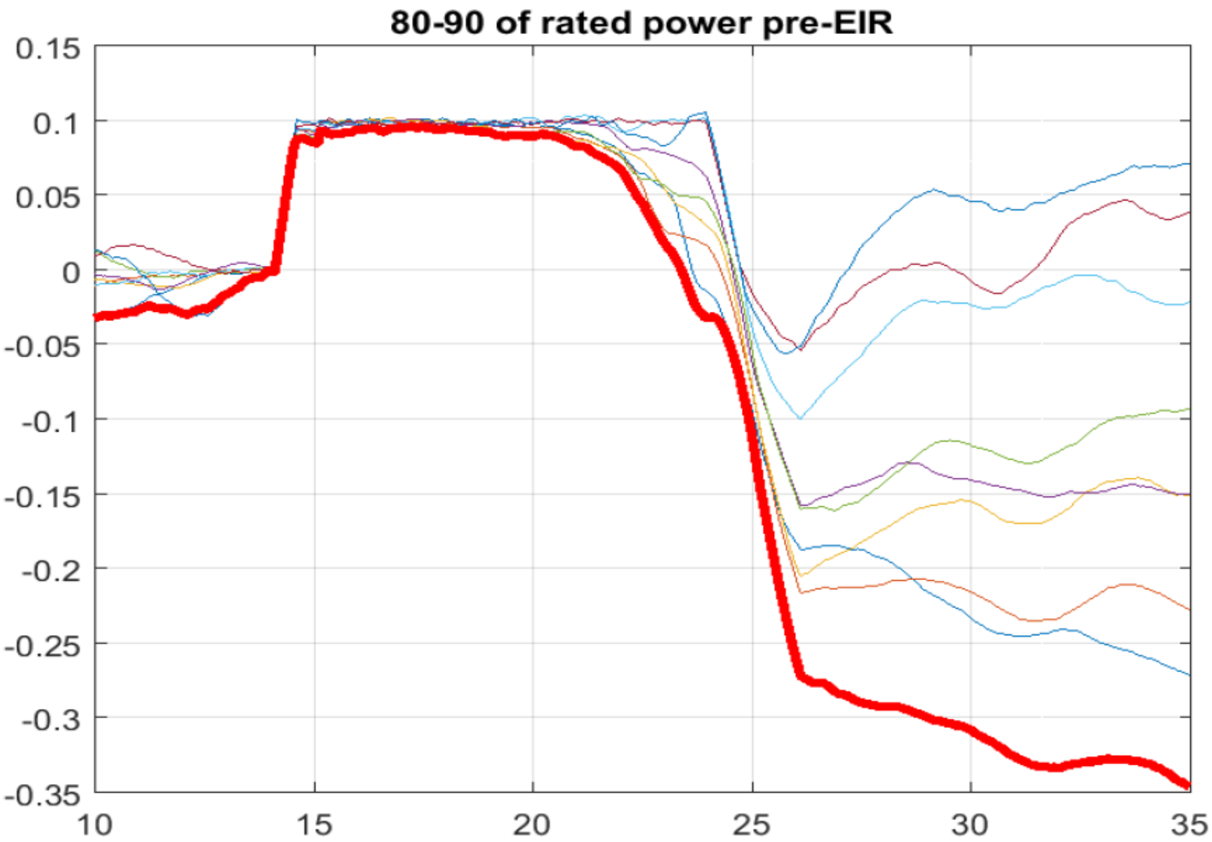


Single Turbine Test – Part Two

- 10 % power for 10 seconds.
- Drop in wind speed.
- During recovery a couple of turbines struggle to stay at the minimum power level, but the others can compensate

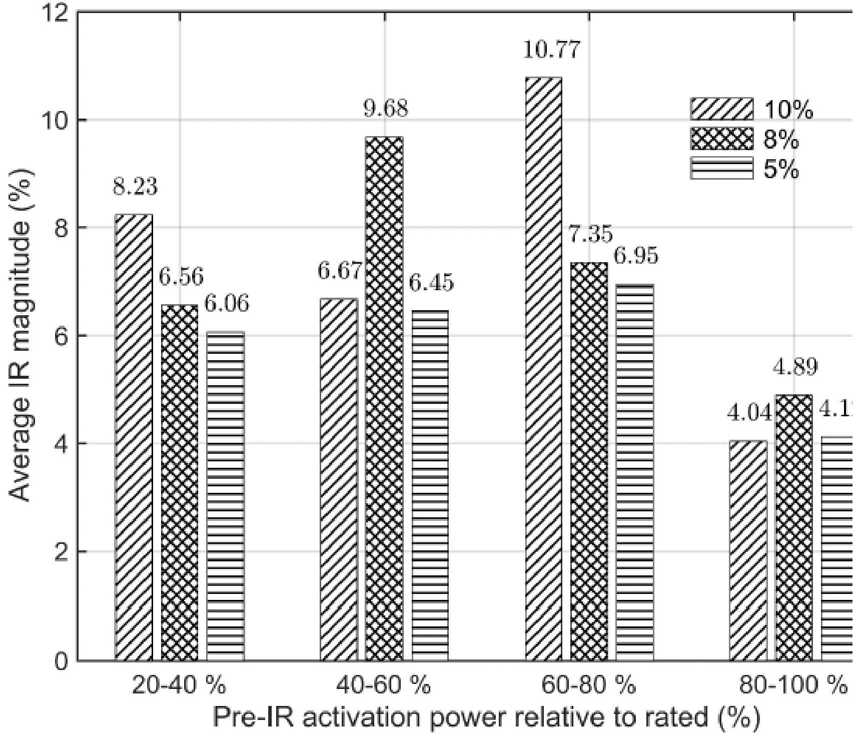


Simulated wind power plant trial

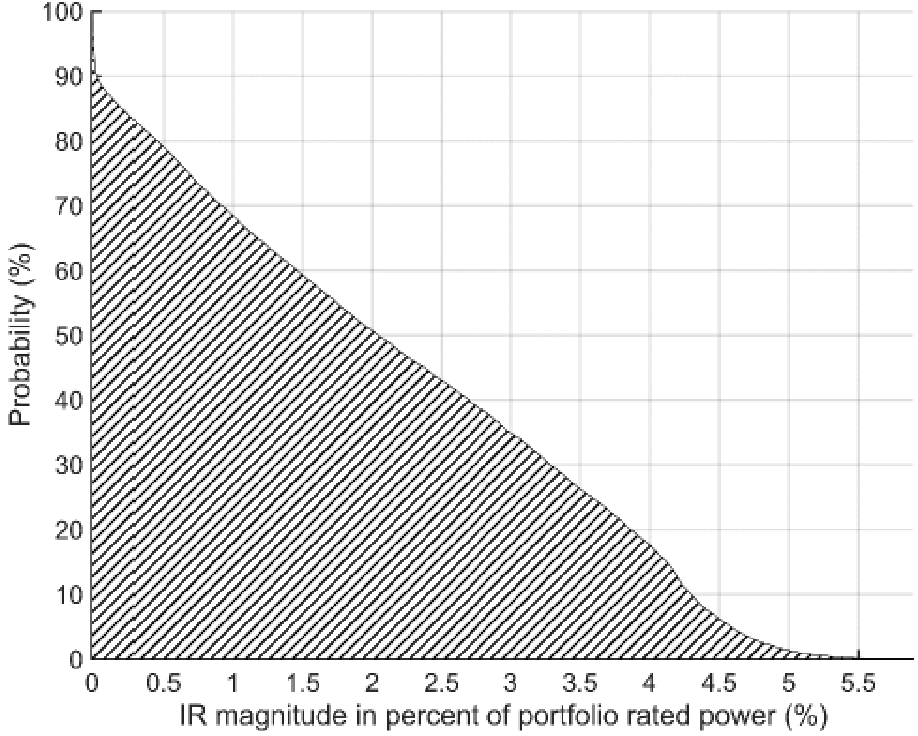


Modelling of Inertial Response - Wind data (2017)

- Magnitudes (IR)



- Delivery across portfolio (IR)



Results

- Fast acting upwards response is possible at no curtailment.

- A recovery period of similar or higher energy than the injected.
  - Hard to estimate a minimum response.
  - The recovery period must be handled by other parts of the system.

- Closed loop control of IR can mitigate recovery.

- Compromise between maximum dip, recovery time and energy injected.

Next steps

- The IR function is to be tested on a **full scale operational wind power plant.**
  - Averaging the responses.
  - Control aspects to mitigate recovery period
- If not possible, SGRE to provide tests from other sites.
- Develop frequency market to **accommodate** wind power and other **stochastic resources**.

Wind Power

Commercial insights

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Summary of wind power commercial products

1 Downward frequency response

- All Ørsted Wind farms can provide downward (e.g., High) frequency response in **under a second**
- This response is **predictable** - Response characteristics are identical across a very wide range of wind conditions

2 Upward Frequency response (with downregulation)

- Orsted Wind farms can provide upward (e.g., Primary and Secondary) response provided wind farms are downregulated
- Wind farms can be downregulated by NG using a mechanism such as BOA – Ørsted is keen to provide data to NG to help enable downregulation, and show upward response capabilities

3 Upward Frequency response (from inertia)

- Wind farms can provide sub second upward response (e.g., a pre-primary product) **without being downregulated**
- This response called ‘ inertial response’ takes kinetic energy from moving parts of turbines to inject energy in for a short period (e.g., 10% of energy for 10s)

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Three core benefits from wind providing Frequency Response

	The problem	How wind helps
Reduced deviation of frequency	▪ **Decreasing inertia** is one of the critical issues being faced by National Grid ▪ In a low inertia environment, frequency swings are more likely	▪ The speed (**sub 1 second delivery**) of Orsted's upward and downward response will **reduce the deviation** from nominal.
No additional CAPEX required	▪ Solutions to reduced inertia often require **large CAPEX investments**, e.g., batteries	▪ Investment decisions have already been made; Windfarms capabilities do **not require any additional CAPEX**
Increasingly important part of the system	▪ Conventional providers are **being retired** from the system ▪ Alternative fast response technologies would need to be brought onto the system specifically	▪ Offshore wind is an increasingly large part of the UK system ▪ This is **set to grow over the next few years** as offshore wind prices continue to fall

The market must evolve in two fundamental ways

	The problem	Change required
Value fast response	▪ Current markets are not inclusive - they do not distinguish between slow assets that take up to 10 seconds to respond, and faster assets such as wind. ▪ **Fast responders are at a disadvantage** as they are not paid for the first 10 seconds of response in current Primary and High markets.	▪ Value fast response above slower response ▪ Consider creating a **'Pre-primary' product**; this could be specifically useful for the 'inertial response' product
Procure response for shorter periods, closer to delivery time	▪ Current FFR markets procure response for an entire month – this is **not an inclusive market** ▪ Wind and other renewables cannot participate in this market since these are stochastic sources of energy	▪ Move to a day ahead market, with defined time intervals - such as the four-hour time periods prevalent in German response markets –allowing **offshore wind to bid** into the market **with large, predictable quantities**

Key conclusions

Current	Wind can deliver products currently capable of participating in a fast acting frequency support market – just like solar and batteries.
Future	Wind can use the **kinetic energy** to provide a short burst of **upregulation** when needed the most.
Commercial	The market must change to **accommodate** and value **fast acting services** and allow for **stochastic resources**.

Enhanced Frequency Control Capability

Wind Power Package

Tak for opmærksomheden.
Thank you for the attention.

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Q&A